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Summary

The attached draft report considers the technical impact of introducing a GSM service onboard aircraft. It provides the preliminary results of the investigation of the compatibility between GSM equipment (including noise generating equipment) used onboard aircraft and terrestrial networks: GSM900, GSM1800, IMT-2000/UMTS 2 GHz.

The study focuses on the compatibility of the system with terrestrial networks when the airborne system is working above an altitude of 3000 metres above ground. Both the Minimum Coupling Loss and SEAMCAT simulation methods are used for different scenarios studied. The simulation results and hence the probability of harmful interference are strongly dependent on the assumptions of the several input parameters, many of them requiring more studies before final conclusions can be made.

The study does not include the regulatory and operational aspects or compatibility with the aircraft avionics.

Proposal

WGSE is invited to consider the attached draft ECC Report and to decide whether further studies, as indicated in the Report, are necessary for the completion on the Report before its final adoption, possibly in February 2006.

Background

Project Team SE7 was tasked by WGSE in February 2005 to study compatibility between GSM equipment used onboard aircraft and terrestrial networks and to produce an Interim Report by June 2005 and a Final Report by October 2005. WGSE adopted the Interim Report in June 2005 and gave guidance to the SE7 for its further work.

REPORT
ON THE COMPATIBILITY BETWEEN GSM EQUIPMENT ON BOARD AIRCRAFT AND TERRESTRIAL NETWORKS

Issue 0.4

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EXECUTIVE SUMMARY

This report considers the technical impact of introducing a GSM service onboard aircraft. It provides the results of the investigation of the compatibility between GSM equipment (including any added equipment onboard if needed) used on board aircraft and terrestrial networks, including at least GSM900, GSM1800, IMT-2000/UMTS.

The study focuses on the compatibility of the system with terrestrial networks when the airborne system is working above an altitude of 3000 metres above ground. Note that the study does not include the regulatory and operational aspects or compatibility with the aircraft avionics.

[Conclusions from report will be added later on].

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DRAFT REPORT

ON THE COMPATIBILITY BETWEEN GSM EQUIPMENT ON BOARD AIRCRAFT AND TERRESTRIAL NETWORKS

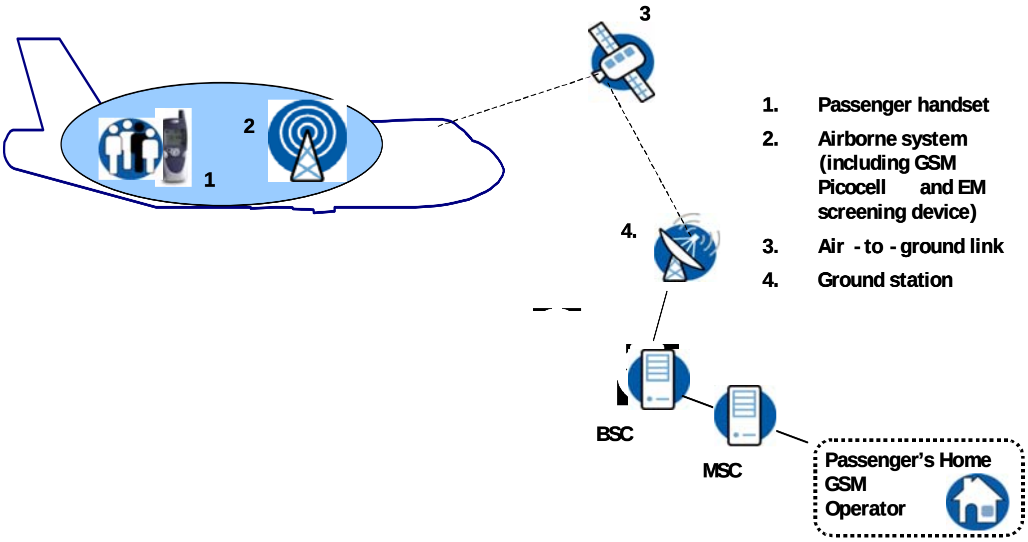
1 INTRODUCTION

1.1 Scope of this report

This report considers the technical impact of introducing GSM services onboard aircraft. The purpose of this work is to investigate the compatibility between GSM equipment (and any required additional equipment) used onboard an aircraft and terrestrial networks. Specifically, this report addresses the impact of the GSM onboard aircraft system on terrestrial GSM and UMTS networks. The GSM onboard aircraft system is assumed to operate in the GSM1800 band. Given that nowadays many mobile terminals are multiband or multimode terminals, and considering that some preliminary studies have shown that interactions between mobile terminals located onboard aircraft and terrestrial networks are possible, this report addresses GSM900, GSM1800 and UTRA-FDD 2GHz terrestrial networks.

The geographical scope of this report is the CEPT area.

The following picture shows an overview of such a system: an onboard cell is linked to the backbone terrestrial networks with a satellite link:



1.2 Terrestrial frequency bands and systems covered in this report

The study assumes that the GSM onboard aircraft system covers the following terrestrial frequency bands to connect the mobile terminals located onboard an aircraft (connectivity) and to prevent interaction with terrestrial systems (control):

<u>Connectivity</u>: 1710-1785 MHz and 1805-1880 MHz (GSM1800)

<u>Control</u>: 876-915 MHz and 921-960 MHz (GSM900 including GSM-R)

1710-1785 MHz and 1805-1880 MHz (GSM1800)

1920-1980 MHz and 2110-2170 MHz (UMTS UTRA-FDD 2GHz)

This report addresses the operation of the GSM onboard aircraft system above 3000 metres above ground. Below 3000 metres above ground the GSM onboard aircraft system (including all the equipment needed) is assumed not to be transmitting accordingly with aircraft operational procedures.

1.3 Issues for future study not covered in this report

This report is limited to the above mentioned frequency bands and systems.

1.3.1 Connectivity bands

This report only deals with GSM 1800 band for connectivity. The reason of this choice, proposed by potential onboard operators, is mainly technical (e.g.: Propagation is more appropriate in the GSM 1800 band, impossibility to settle the minimum EIRP at 0 dBm at 900 MHz). However, the use of the GSM 900 could be envisaged as a connectivity band in futures studies.

1.3.2 Control bands

Other frequency bands and systems that could potentially be affected by a GSM onboard aircraft system depending on flight routes, capabilities of terminals carried onboard and future terrestrial network deployments include:

- [NMT450]
- CDMA450 and CDMA-PAMR
- [GSM850]
- [CDMAOne]
- UMTS900
- UMTS1800
- [GSM1900]
- UTRA-TDD in the 2 GHz TDD bands
- UTRA-FDD and TDD in the 2.6 GHz extension band
- Other IMT-2000 systems operated in IMT-2000 frequency bands (e.g.: CDMA2000)
- PMR/PAMR services in the 870-876/915-921MHz band

These frequency bands and systems could be addressed in future studies as appropriate.

1.3.3 Other aspects

This report does not cover the impact of terrestrial networks on the GSM onboard aircraft system. Such scenarios could be addressed in future studies.

Furthermore this study does not include consideration of regulatory and operational aspects nor compatibility with the aircraft avionics.

2 ACRONYMS, ABBREVIATIONS and DEFINITIONS

ac-BTS	GSM base station located onboard
ac-MS	GSM mobile station located onboard
ac-UE	UMTS User Equipment located onboard
Antenna pattern	refers to modelization by a set of formulas (e.g.: an ITU-R recommendation)
Antenna diagram	refers to real characteristics (e.g.: measurements)
FAR	Federal Aviation Regulations

FDD	Frequency Division Duplex
g-BS	UMTS base station located on the ground
g-BTS	GSM base station located on the ground
g-MS	GSM mobile station located on the ground
g-UE	UMTS User Equipment located on the ground
GPRS	General Packet Radio Service
MCL	Minimum Coupling Loss
NCU	Network control Unit located onboard
Receiver Noise Figure (dB)	Receiver noise figure is the noise figure of the receiving system referenced to the receiver input. (According to official 3GPP Vocabulary TR21.905)
Receiver Sensitivity (dBm)	This is the signal level needed at the receiver input that just satisfies the required Eb/(No+Io). (According to official 3GPP Vocabulary TR21.905)
SEAMCAT	Spectrum Engineering Advanced Monte-Carlo Analysis Tool
TDD	Time Division Duplex
UMTS	Universal Mobile Telecommunications System
UTRA	UMTS Terrestrial Radio Access
3GPP	Third Generation Partnership Project

3 DESCRIPTION OF SERVICE AND ENVIRONMENT

3.1 Service description

Onboard GSM mobile services would allow airline passengers to use their personal mobile phones during approved stages of flight. Passengers can make and receive calls, send and receive SMS text messages and use GPRS functionality. The system provides a mobile visited network access.

3.2 Service environment

Onboard GSM mobile telephony services are to be deployed into aircrafts intended for both national and international flights. Various terrestrial networks are deployed in those countries. It is highlighted that:

- The frequency band used for onboard communications is the one used by GSM 1800,
- Most of the user terminals are multiband or multimode, so they are able to transmit in other frequency bands than the one used by GSM 1800 (e.g: GSM 900, UMTS 2 GHz),
- The corresponding terrestrial network may be impacted by the onboard terminal.

The system adopted therefore ensures that user terminals on an aircraft are unable to attempt to communicate with ground networks, whilst providing onboard connectivity. When there is no onboard connectivity, passengers must switch off their mobile phone in order to unable communication with ground network. Terminal not compatible with GSM networks shall be switched off during all the flight.

There are several technical and operational methods by which the electromagnetic isolation between the onboard system and the terrestrial networks can be achieved, One of them using the “network control unit” is described in chapter 4 and the corresponding scenarios and simulations are detailed in chapter 5. Other potential technical or operational methods to satisfactory the electromagnetic isolation requirements are listed in the mitigation factors and techniques section in section 9 of this report.

4 End-to-end Description of a system using the NCU solution

4.1 Introduction

The system provides visited network access for GSM subscribers wishing to make or receive mobile communications while onboard aircraft. In this chapter, an example implementation of a system using a Network Control Unit (NCU) is described. At this detail level, alternative implementations are possible.

This chapter focuses on one possible implementation of a GSM on board aircraft system. Other possible implementations of the system on board aircraft could be deployed by operators in order to achieve GSM coverage of an aircraft by using for example multiple leaky cable configurations.

4.2 General architecture

The onboard GSM BTS and the NCU are operational during the top of ascent, cruise and commencement of descent phases of the flight. These are the stages of the flight where the aircraft is not less than 10,000 feet (3,000 metres) above ground level. This is in accordance with EASA (European Aviation Safety Agency) rules [and Part 121 and Part 135 in the Federal Aviation Regulations], which define the critical phases of flight. In practice, cruise altitude is usually substantially higher than this.

The system typically consists of the airborne and ground segments, subdivided in two domains, see figure 1).

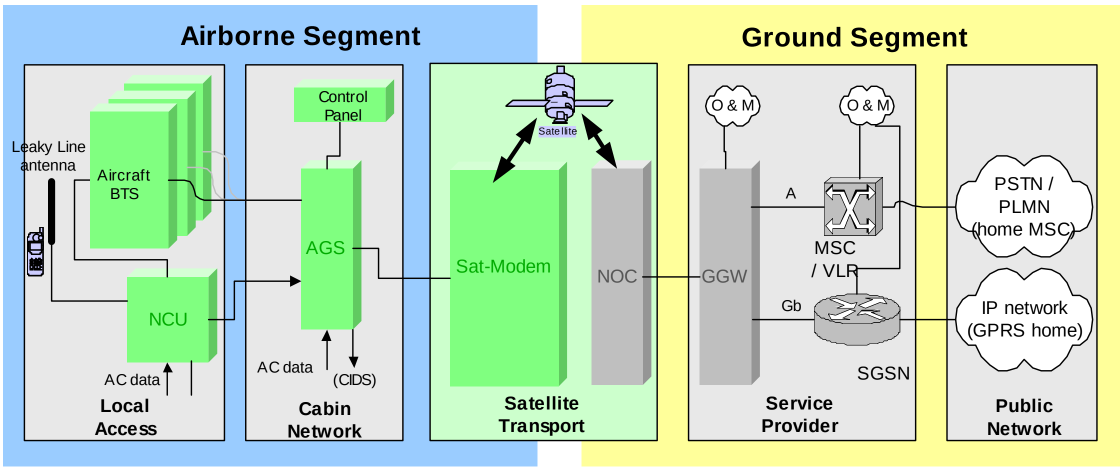


Figure 1: Overall end to end Architecture of the onboard GSM system

The airborne segment consists of the local access domain and the cabin network domain:

- The local access domain contains the BTS (Base Transceiver Station) providing GSM access for passengers' mobile phones and the NCU. The purpose of the NCU in conjunction with the pico cell is to prevent mobile phones from accessing terrestrial networks and control the radio frequency emissions of all mobile stations (MSs) transmitting in GSM 900, GSM 1800 and UMTS UTRA FDD 2 GHz.
- The cabin network domain contains an aircraft GSM server (AGS) that integrates the main modules onboard, i.e. the BTS, the NCU and the Sat-Modem.

The ground segment consists of a service provider domain and the public network domain.

- The service provider domain hosts communication controller functions that act together with the AGS functions in the aircraft. For this purpose, a Ground Gateway (GGW), and GSM visited network components (VMSC and SGSN) are required. Their main features are to perform the routing towards the aircraft, and to interconnect the aircraft traffic with terrestrial backbone networks of the Public Network Domain.
- The public network domain provides the interconnection of the call, data or signaling communication to the relevant public network end points.

The satellite transport link connects the airborne and the ground segments.

Note that the system description only describes the elements related to the on board GSM service and does not include aircraft systems, such as the avionics, as these are out of scope of this report.

4.3 System components of the airborne section

The following highlights the main components of the onboard GSM system present on the aircraft.

4.3.1 Cabin Antenna

The cabin antenna transmits and receives the RF signals within the cabin. The antenna is typically a leaky line, installed along the entire cabin behind the ceiling panels. The ac-BTS and NCU share the same antenna solution.

4.3.2 AGS – Aircraft GSM Server

The AGS forwards the data streams between the BTS and the ground. The AGS manages the satellite link communication, controls the BTS, monitors the NCU output power level and manages the Operations and Maintenance (O&M) functions.

4.3.3 Control panel

The control panel is the physical interface where the system can be manually accessed. The control panel will display relevant system information, including the status indication (on/off, major or minor failure).

4.3.4 CIDS Input: Cabin Intercommunication Data System

CIDS is the Cabin Intercommunication Data System on board the aircraft including but not limited to cabin lights, seatbelt signs, and passenger announcements.

4.3.5 AC Data: Aircraft Data

The aircraft data contains aircraft information including but not limited to altitude, aircraft position and flight phase.

4.3.6 Onboard Satellite components

The on board satellite components consist of the satellite modem and the external aircraft satellite antenna. The satellite antenna receives and transmits the signals from/to the satellite system.

4.3.7 The Network Control Unit (NCU)

The NCU ensures that ac-MSs within the cabin cannot access terrestrial networks and that they do not transmit any signal without being controlled by the onboard GSM system, this is necessary for the operation of the pico cell ac-BTS. The NCU removes terrestrial visibility onboard the aircraft by raising the noise floor inside the cabin.

The legal status of the NCU is outside the scope of this report

The European configuration of the onboard network control unit has the following characteristics:

o

- No transmission below 3000 m above ground;
- Dedicated Minimal power to screen terrestrial networks inside the aircraft and only transmitted at above a certain altitude (power value dependent on frequency used and altitude);
- The power level may be reduced with increased altitude because of the decreased signal strength received in the aircraft from terrestrial networks;
- Covers entire GSM and UMTS BTS/Node B to Mobile (downlink) bands.
    - GSM 900 including GSM-R (921-960 MHz);
    - GSM 1800 (1805-1880 MHz);
    - UMTS UTRA-FDD 2GHz (2110 – 2170 MHz).

For operation in others regions of the world other bands should be covered by the NCU.)

4.3.8 The GSM connectivity component (aircraft BTS)

The GSM connectivity component comprises of a BTS on the aircraft, which establishes the communication access to the MS in the aircraft and supports all necessary system features like radio access and radio resource management. Given that the NCU transmits contiguously across the whole band the GSM connectivity component will have to transmit at a higher power level.

The GSM aircraft BTS for Europe has the following characteristics:

- Support of standard GSM and GPRS services;
- Low spectrum usage (up to 5 GSM 200 KHz carriers);
- Operating in the 1800 MHz spectrum band over Europe;
- Operating at sufficient margin (at least 9dB)over the NCU power level.

4.3.9 Onboard GSM Mobile Station (MS)

Whilst strictly not part of the onboard system, passengers' MSs will need to be evaluated in conjunction with the onboard system.The onboard MSs in Europe will have the follow characteristics:

- GSM access in the 1800 MHz bands for communication;
- Transmission (uplink) power reduced to the minimum possible power level, of 0 dBm.

4. 3. 10 Unwanted emission requirements of the onboard system using the NCU solution

The pico network system using an NCU solution is subject to the R&TTE Directive. The Directive's mechanisms therefore will be used to determine the essential requirements to place such a system on the market via the definition of a harmonized standard or via the approval of a technical construction DCF file route (according to R&TTE Annex 4).

Given that the system using the NCU solution comprises of an NCU, the pico cell and any mobile phone brought onboard by the passenger, it is clear that the harmonized standard will define the unwanted emission requirements in order to satisfy the requirements highlighted in ITU-R (SM. 329-10) and CEPT (ERC Rec. 74-01) recommendations.

5 IDENTIFICATION OF SCENARIOS

Onboard GSM mobile services allow airline passengers to use their personal mobile phones during approved stages of national and international flights.

The system adopted ensures that user terminals on an aircraft are unable to attempt to communicate with ground networks, whilst providing onboard connectivity (the frequency band used is the GSM 1800 band).

Therefore, this report studied[1] the impact of the:

- a/c-NCU emissions in the Terrestrial Downlink (g-BTS → g-MS link);
- a/c-BTS emissions in the Terrestrial Downlink (g-BTS → g-MS link), at 1800 MHz only;
- a/c-MS emissions in the Terrestrial Uplink (g-MS → g-BTS link)

[1] Note that this report doesn't address regulatory aspects or compatibility issues with the aircraft avionics.

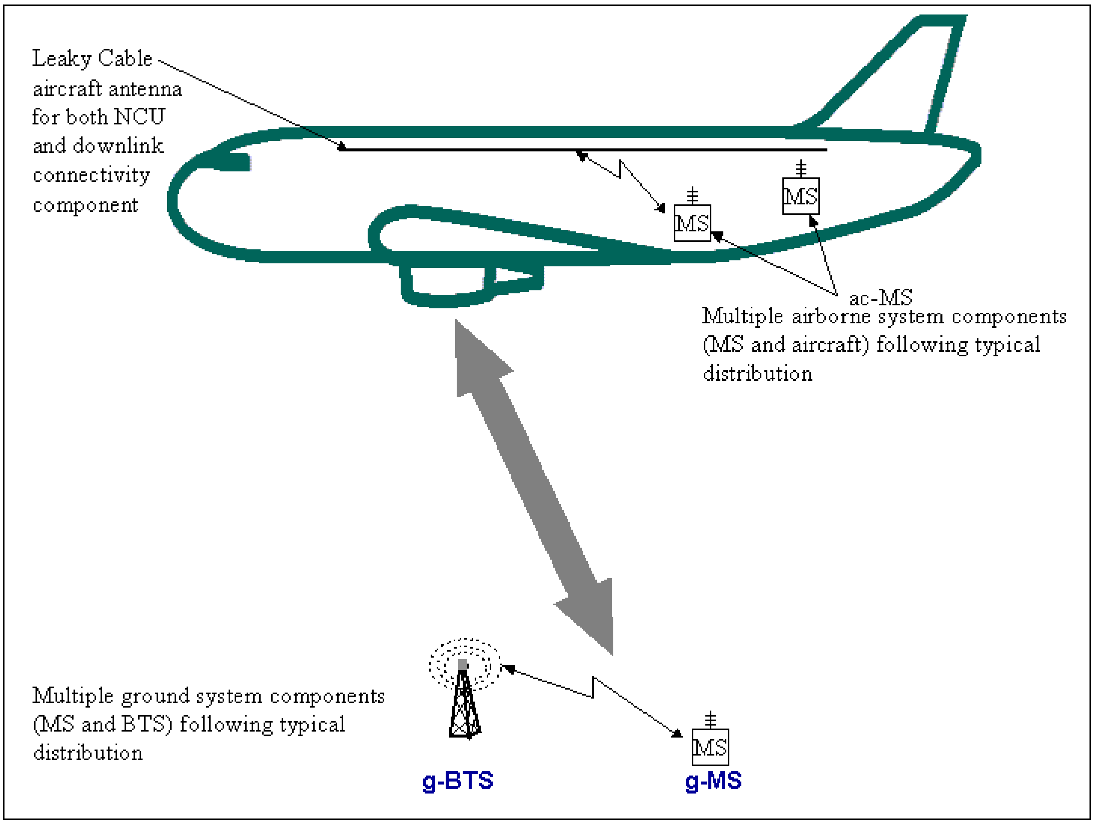


Figure 1.: Onboard GSM and terrestrial cellular system analysis

The following 6 scenarios were studied:

- Scenario 1: Impact of the Terrestrial g-BTS in the onboard a/c-MS. This scenario, using MCL approach, will assess in which conditions the onboard a/c-MS will have visibility from the Terrestrial Networks. Note that the NCU/BTS onboard are not present here.
- Scenario 2: Impact of the onboard a/c-MS in the Terrestrial g-MS→g-BTS link. This scenario, using MCL approach, will assess in which conditions the onboard a/c-MS will have capacity to connect to the Terrestrial Networks. Note that the NCU/BTS onboard are not present here.
- Scenarios 3 and 4: Impact of onboard NCU (and a/c-BTS) emissions in the Terrestrial Downlink (g-BTS→g-MS link).
- Scenarios 5 and 6: Impact of onboard a/c-MS emissions in the Terrestrial Uplink (g-MS → g-BTS link).

The SEAMCAT scenarios definition approach has been used to define the scenarios necessary to understand the impacts between the two systems (Terrestrial and onboard GSM).

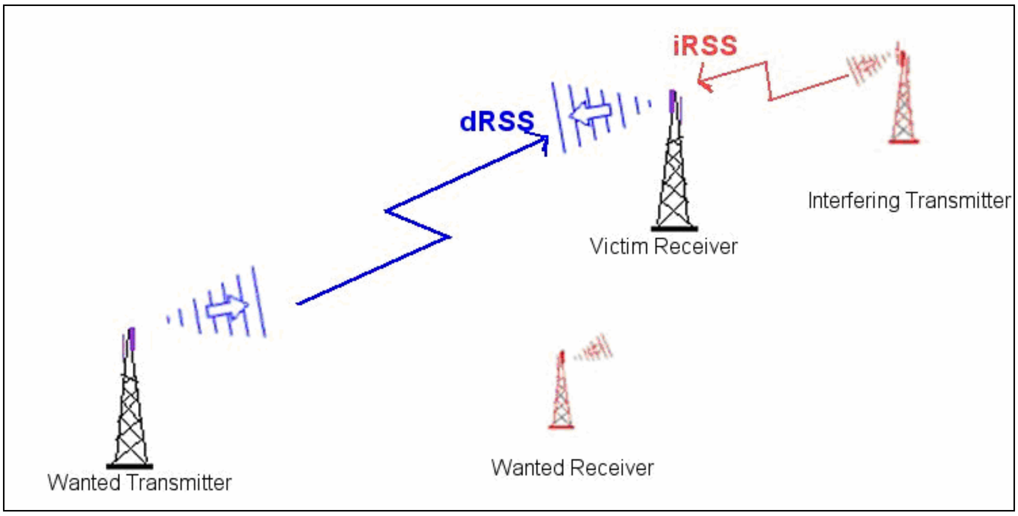


Figure 2: SEAMCAT Scenario Definition

5.1 Scenario 1: No onboard network g-BTS to ac-MS (downlink)

This scenario will assess in which conditions the onboard a/c-MS will have visibility from the Terrestrial Networks, by using MCL calculations. It was identified as a starting point for the study and the results will be used as inputs for scenarios 3 and 4.

This scenario consists of one terrestrial BTS network (using various cellular bands), with no system onboard - no connectivity system and no network control unit.

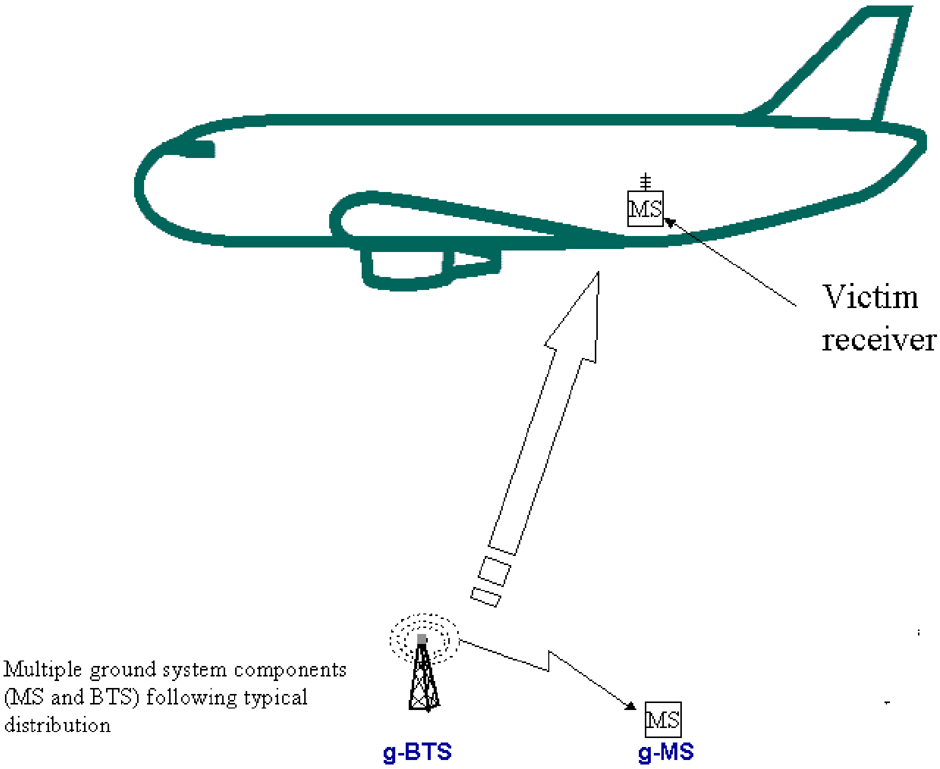


Figure 3: Capacity of g-BTS signal being received in aircraft

Number of aircraft	1
Altitude of the aircraft above ground level	3000 m to 10000 m
Elevation	Various angles with g-BTSs
Interfering transmitter	1 g-BTS
Position of transmitter	Static
Transmitter frequencies	900, 1800, 2,000 MHz
Technologies	GSM and UMTS
Path loss between aircraft and ground networks	Free space path loss
Victim receiver	1 ac-MS
Criteria	Received power by ac-MS from g-BTS/Node B (GSM or UMTS) compared to ac-MS sensitivity as function of altitude
Aim	Assess if a mobile device on an aircraft will have visibility to the ground networks
Modelling approach	MCL
Simulation cases	1) GSM 900 2) GSM 1800 3) UMTS 2000

5.2 Scenario 2: No onboard network ac-MS to g-BTS (uplink)

This scenario will assess in which conditions the onboard a/c-MS will have capacity to connect to the Terrestrial Networks, by using MCL calculations.

This scenario consists of one victim link (Terrestrial Uplink), and a single onboard a/c-MS without any system onboard - no connectivity system and no network control unit.

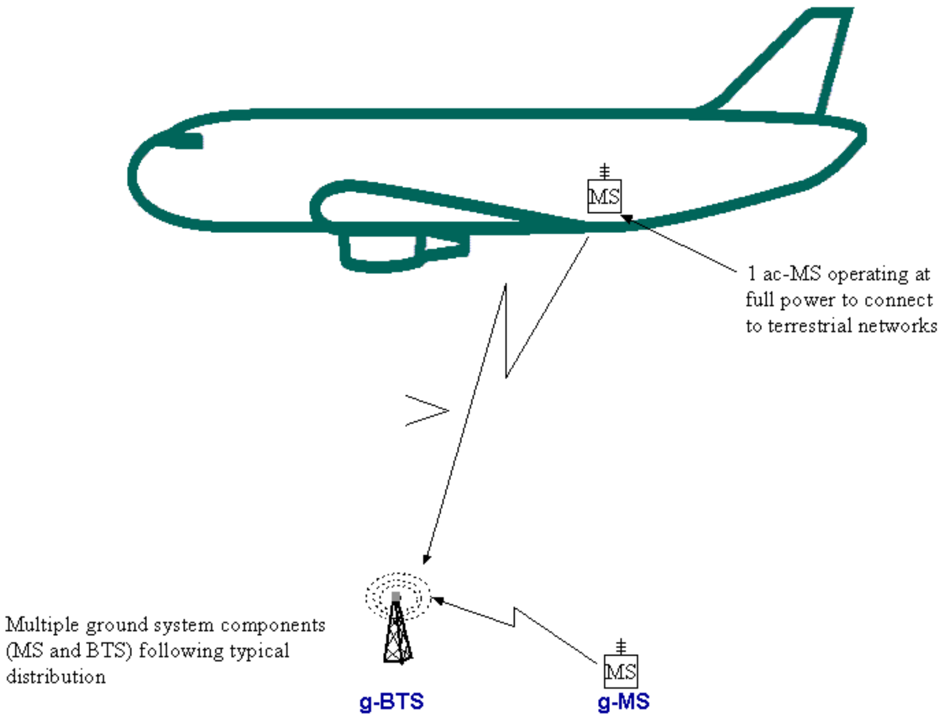


Figure 4: Capacity of ac-MS signal being received at g BTS (no NCU)

Number of aircraft	1
Altitude of the aircraft above ground level	3000 m to 10000 m
Elevation	Various angles with g-BTSs
Interfering Transmitter	1 ac-MS
Intefering Transmitter power	Full power depending on the frequency band
Transmitter frequency	900, 1800, 2000 MHz
Path loss between aircraft and ground networks	Free space path loss
Victim receiver	1 g-BTS
Victim link	Between the aircraft MS and the ground BTS
Criteria	Received power by the g-BTS from ac-MS (GSM or UMTS) compared to g-BTS sensitivity
Aim	Assess the ability of a mobile phone located onboard can successfully communicate to the ground network
Modelling approach	MCL
Simulation cases:	1) GSM 900

	2) GSM 1800 3) UMTS 2000

5.3 Scenario 3: Onboard GSM effects on the terrestrial BTS to MS link (downlink)

This scenario will assess the impact of onboard NCU (and a/c-BTS) emissions in the Terrestrial g-MS receivers, by using SEAMCAT simulations.

This scenario consists of a single interfering link (the NCU and ac-BTS) whose emissions could impact several victim links (Terrestrial Downlinks). Noting that the NCU is ON (at various cellular bands) and there is the onboard connectivity (at 1800 MHz).

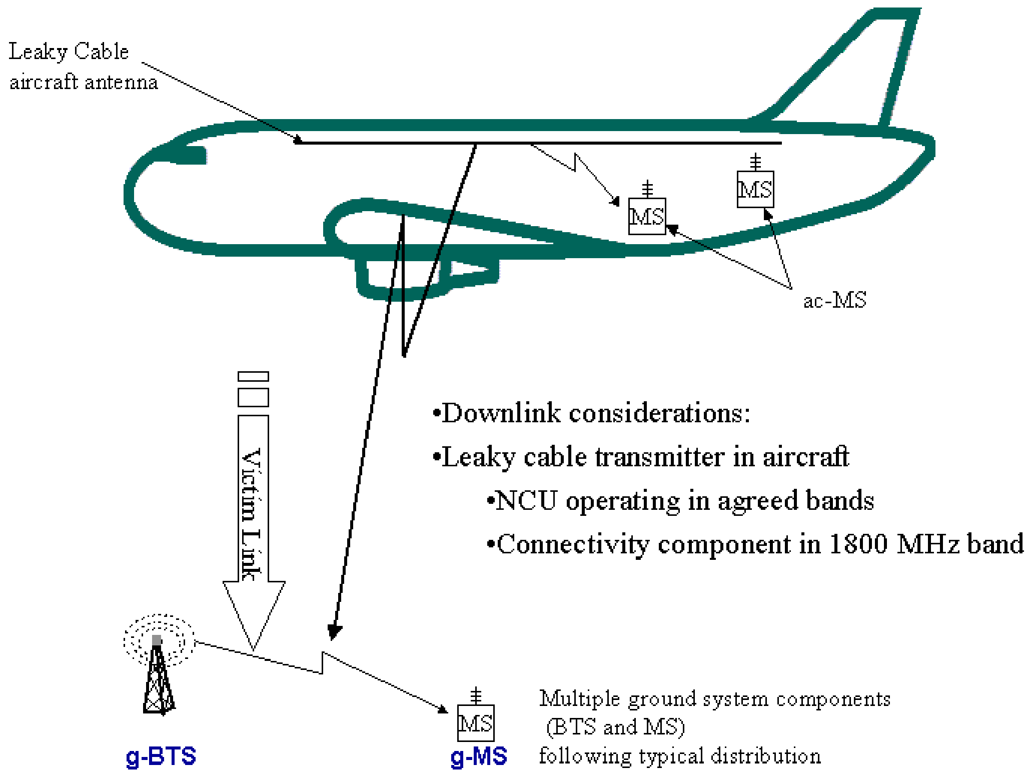


Figure 5: Scenario 3 Probability of interfering victim link (g-BTS to g-MS)

Number of aircraft	1
Altitude of the aircraft above ground level	3000 m to 10000 m
Elevation	Various angles with links
Interfering Transmitter (1)	ac-BTS (Leaky cable)
Transmitter frequency (1)	1800 MHz
Interfering Transmitter (2)	NCU (Leaky cable)
Transmitter frequency (2)	900, 1800, 2000, … MHz
Victim receiver	1 g-MS
Wanted transmitter	1 g-BTS
Victim link	g-BTS to g-MS
Position of victim receiver	Typical outdoor distribution illustrating both noise-limited network and traffic-limited network

Path loss between aircraft and ground networks	Free space path loss
Criteria	Ratio between power received from g-BTS and interfering power received from ac-BTS / NCU compared to g-MS C/(I+N) protection
Aim	To determine the probability of the ac-BTS interfering with the terrestrial BTS to MS communication links. To determine the probability of the NCU interfering with the terrestrial BTS to MS communication links.
Modelling approach	SEAMCAT
Simulation cases	1) NCU Interferer on g-BTS → g MS GSM 900 2) NCU Interferer on g-BTS →g MS GSM 1800 3) Airborne BTS Interferer on g-BTS →g MS GSM 1800 4) NCU Interferer on g-BTS/Node B →g UE UMTS 2000

5.4 *Scenario 4: Onboard GSM effects on the terrestrial BTS to MS links (downlinks) multiple aircraft*

This scenario will assess the impact of several aircrafts, namely their onboard NCU (and a/c-BTS) emissions in the Terrestrial g-MS receivers, by using SEAMCAT simulations.

This scenario consists of multiple interfering links (multiple aircraft) where emissions of their NCU and/or ac-BTS could have impact in a victim link (Terrestrial Downlinks). Noting that the NCU is ON (at various cellular bands) and there is onboard connectivity (at 1800 MHz).

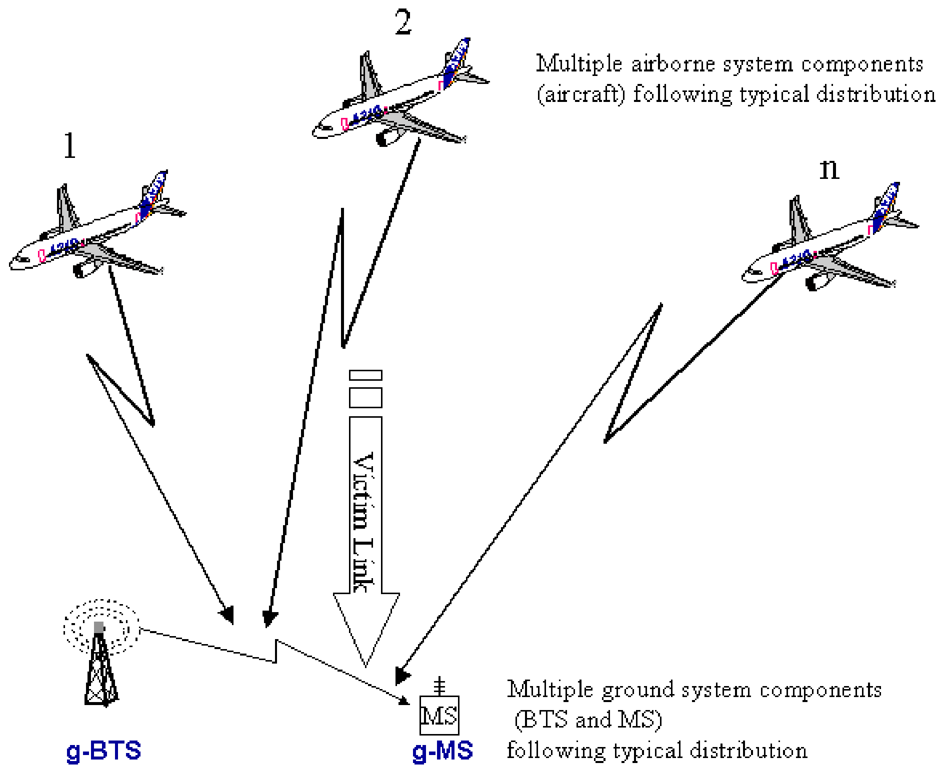


Figure 6: Probability of interfering Terrestrial Downlink (g-BTS to g-MS) for multiple aircraft

Number of aircraft	Airport distribution
Altitude of the aircraft above ground level	Altitude, position and direction distribution
Elevation	Various angles with links
Interfering Transmitter (1)	ac-BTS (Leaky cable)
Transmitter frequency (1)	1800 MHz
Interfering Transmitter (2)	NCU (Leaky cable)
Transmitter frequency (2)	900, 1800, 2000, … MHz
Victim receiver	Several g-MS
Position of victim receiver	Typical MS distribution
Wanted transmitter	g-BTS

Position of wanted receiver	Typical outdoor distribution illustrating both noise-limited network and traffic-limited network
Victim link	g-BTS to g-MS
Path loss between aircraft and ground networks	Free space path loss
Criteria	Ratio between power received from g-BTS and interfering power received from multiple ac-BTS / NCU compared to g-MS C/(I+N) protection
Aim	To determine the probability of the ac-BTS interfering with the terrestrial BTS to MS communication links for multiple aircraft near an airport.
Modelling approach	SEAMCAT
Simulation cases	1) NCU Interferers on g-BTS →g-MS GSM 900 2) NCU Interferers on g-BTS →g-MS GSM 1800 3) Airborne BTS Interferers on g-BTS →g-MS GSM 1800 4) NCU Interferers on g-BTS/Node B →g-UE UMTS 2000

5.5 Scenario 5: Onboard GSM effects on the terrestrial MS to BTS links (uplink)

This scenario will assess the impact of onboard a/c-MS emissions in the Terrestrial g-BTS receivers, by using SEAMCAT simulations.

This scenario consists of several interfering links (ac-MS) whose emissions could have impact on several victim links (Terrestrial Uplinks). Noting that the NCU is ON (at various cellular bands) and there is onboard connectivity (at 1800 MHz).

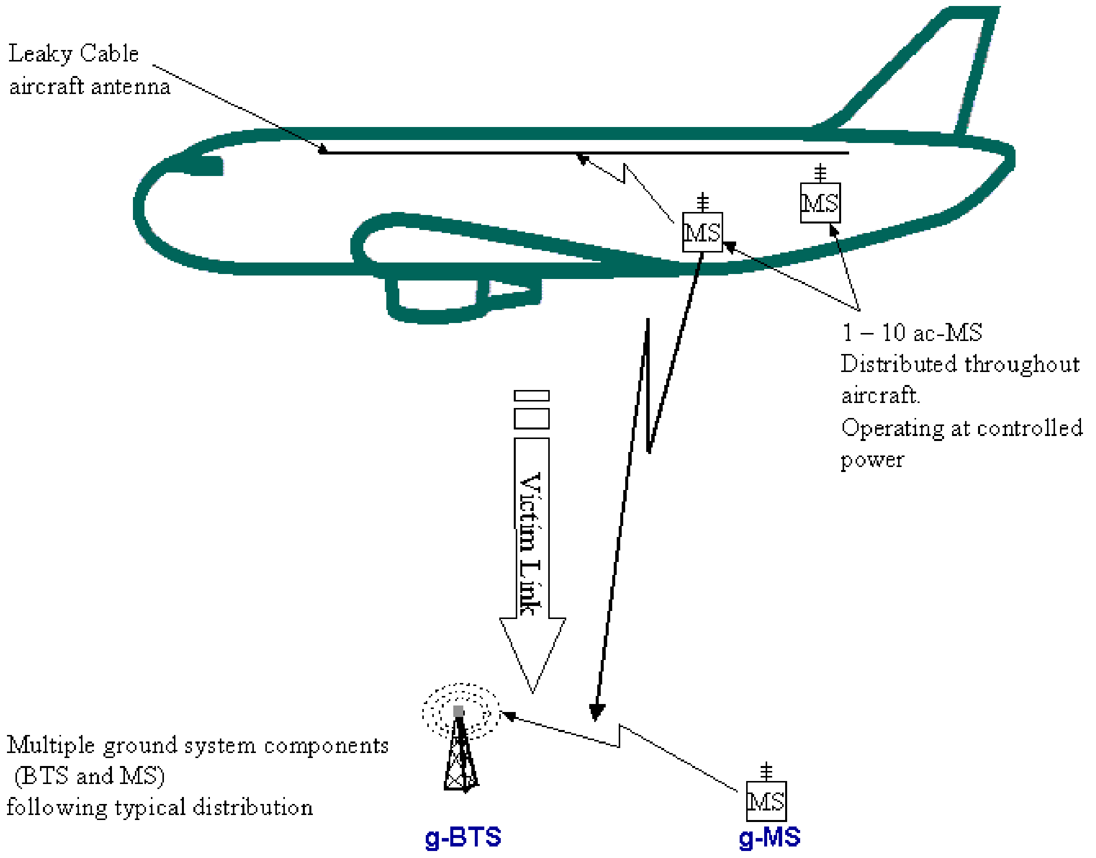


Figure 7: Probability of interfering Terrestrial Uplink (g-MS to g-BTS)

Number of aircraft	1
Altitude of the aircraft above ground level	3000 m to 10000 metres
Elevation	Various angles with links
Interfering Transmitters	Distribution of several ac- MS within the one aircraft
Transmitter frequency	1800 MHz
Victim receiver	1 g-BTS
Position of victim receiver	Fixed

Wanted transmitter	1 g-MS
Position of wanted transmitter	Typical distribution illustrating both noise-limited network and traffic-limited network
Victim link	g-MS to g-BTS
Path loss between aircraft and ground networks	Free space path loss
Criteria	Ratio between power received from g-MS and interfering power received from ac-MS compared to g-BTS C/I protection
Aim	To determine the probability of the ac-MS interfering with a terrestrial MS to BTS communication link.
Modelling approach	SEAMCAT
Simulation cases	ac-MS Interferer on g-MS → g BTS GSM 1800

5.6 Scenario 6: Onboard GSM effects on the terrestrial MS to BTS links (uplink) multiple aircraft

This scenario will assess the impact of onboard a/c-MS emissions in the Terrestrial g-MS receivers, by using SEAMCAT simulations.

This scenario consists of a multiple interfering links(multiple aircraft) where emissions of their ac-MSs could impact a victim link (Terrestrial Uplinks). Noting that the NCU is ON (at various cellular bands) and there is onboard connectivity (at 1800 MHz).

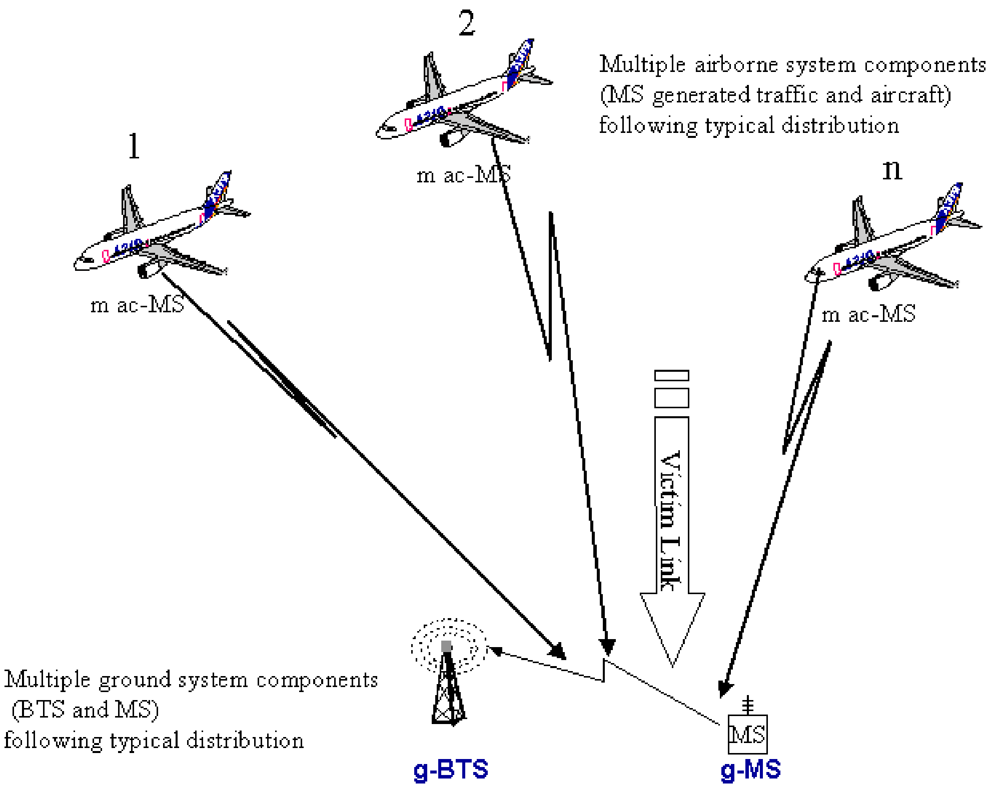


Figure 8 Probability of interfering Terrestrial Uplink (g-MS to g-BTS) for multiple aircraft

Number of aircraft	Airport distribution
Altitude of the aircraft above ground level	Altitude, position and direction distribution
Elevation	Various angles with links
Interfering Transmitters	Assumed average number of mobiles transmitting per aircraft [4]
Transmitter frequency	1800 MHz
Victim receiver	1 g-BTS
Position of victim receiver	Fixed

Wanted transmitter	1 g MS
Position of wanted transmitter	Typical distribution illustrating both noise-limited network and traffic-limited network
Victim link	g-MS to g-BTS
Path loss between aircraft and ground networks	Free space path loss
Criteria	Ratio between power received from g-MS and interfering power received from multiple ac-MS compared to g-BTS C/I protection
Aim	To determine the probability of the ac-MS interfering with the terrestrial MS to BTS communication links for multiple aircraft near an airport.
Suggested modelling approach	SEAMCAT
Simulation cases	ac-MS Interferer on g-MS → g-BTS GSM 1800

6 REFERENCE VALUES

The reference values used in the study are based on figures from the appropriate standards documentation and where applicable current operator values have been added.

6.1 Reference Points on Receiver

Given the various combinations by which the BTS cabinet and antenna complex can be configured the following highlights two main cases and provides values to derive parameters between the test ports highlighted.

6.1.1 Reference case 1: Basic case: only cable loss and connector loss

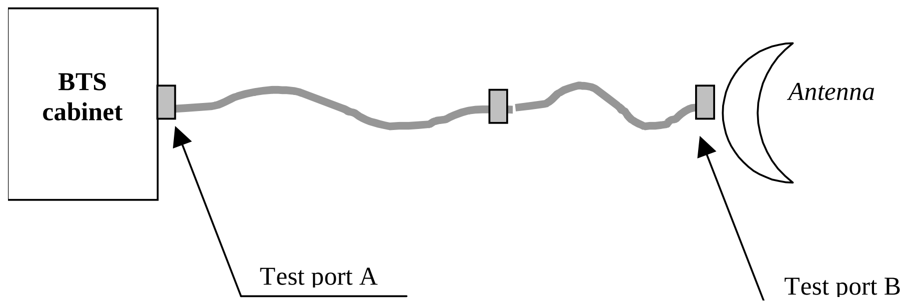


Figure 9: BTS Reference Case 1 (No LNA)

Reference case 1 reflects the configuration assumed for the values referred to in the 3GPP specifications. It consists of a BTS cabinet and antenna where only cable loss and connector loss are considered.

- Derived value (from specifications) for Noise Figure at point A: 8 dB.

- Noise Floor at point A (GSM BTS): -113 dBm.
- Typical cable and connector loss: 3 dB.
- Resulting Noise Figure at point B: 11 dB.
- Resulting Noise Floor at point B (GSM BTS): -110 dBm.

6.1.2 Reference case 2: Typical deployed case: LNA mounted close to the antenna, frequency diversity

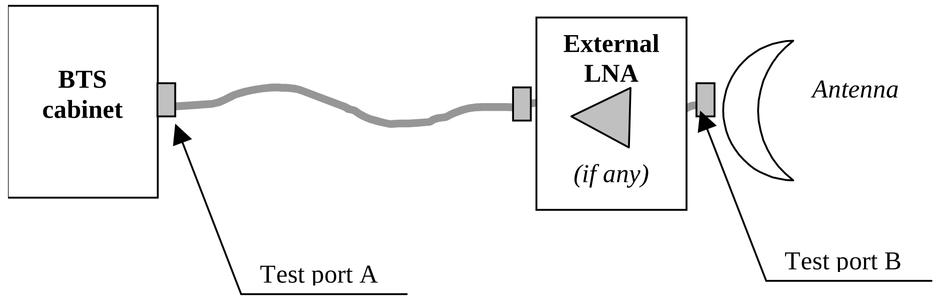


Figure 10: BTS Reference Case 2 (LNA included)

Reference case 2 reflects the configuration assumed for typical operator configuration. It consists of; a BTS cabinet, a low noise amplifier and associated antenna; losses due to multiple carriers sharing the same antenna are not included.

- Typical Noise Figure for LNA: 2 dB.
- Typical cable and connector loss: 3 dB.
- Resulting Noise Figure at point B: 4 dB.
- Resulting Noise Floor at point B : -117 dBm.

6.2 Terrestrial network Reference parameters used for modelling

6.2.1 Reference values according to WGSE mandate

The following bands and cellular technologies have been identified for the compatibility study according to the mandate from WGSE.

- 900 MHz band using GSM technology
- 1800 MHz band using GSM technology
- 2 GHZ band using WCDMA/UMTS technology

Table 1 provides the parameters used in the study according to frequency bands and technologies detailed in the WGSE mandate.

Parameter		GSM 900		GSM 1800		UMT 2GHz	
		MS	BS	MS	BS	UE	NodeB
Antenna input Power	dBm / channel	33	43	30	43	21	33*
Receiver bandwidth	KHz	200	200	200	200	3840	3840
Shielding factor **	dB	0	0	0	0	24	NA***
System noise figure (taken from values quoted in standards)	dB	12	8	12	8	9	5
System noise figure (operator quoted “typical” values)	dB	7	4	7	4	7	4
Noise level (taken from values quoted in standards)	dBm / channel	-109	-113	-109	-113	-99	-103
Noise level (“typical” operator values)	dBm / channel	-114	-117	-114	-117	-101	-104
Receiver Sensitivity (taken from values quoted in standards)	dBm / channel	-102	-104	-102	-104	-117	-121
Receiver Sensitivity (“typical” operator values)	dBm / channel	-105	-108	-105	-108	-119	-122
Interference criteria C/I+N	dB	9	9	9	9		
Min S/N for voice service	dB	9	9	9	9		
Channel Spacing	kHz	200	200	200	200	5000	5000
Receiver Bandwidth	kHz	200	200	200	200	3840	3840

Table 1

*Typical operator power levels for the UMTS pilot channel = max Input power (43 dBm) -10 dB = 33dBm as per UMTS defined testing procedures. As the NCU does just aims to prevent an ac-MS from connecting to a terrestrial network, the NCU has just to screen this pilot channel, given that
1) The mobile will have to be switched off at the beginning of the flight
2) Hence all mobiles will have to register to the network before having any communication
3) The mobile MUST read the pilot channel before it can synchronise and then recognise the network to register
** Shielding factor : the additional power that the inserted noise has to exceed the received terrestrial signals in order to remove visibility of terrestrial network in the cabin.
***The system gain is not applicable to the NodeB because not used in the simulations.

The reference values taken from standards documentation are based on those values used in 3GPP TR 45.050v6.2.0 and 3GPP TR 25.492 v 6.4.0 and ITU M 2039

6.2.2 Reference values for additional bands under study in Europe

The following additional bands and cellular technologies have been included [to be confirmed as soon as the simulations are over] in the compatibility study.

- 900 MHz band using WCDMA/UMTS technology
- 1800 MHz band using WCDMA/UMTS technology
- 450 MHz band using CDMA 2000 technology

Table 2 provides the parameters required to study these additional bands and technologies.

Parameter		UMTS 900		UMTS 1800		CDMA 450	
		UE	Node B	MS	MS	MS	BS
Antenna input Power	DBm	21	TBD	TBD	33*	TBD	TBD
Noise level	dB/channel	-96	TBD	TBD	-103	TBD	TBD
Receiver Sensitivity (standard)	DBm/channel	-114	TBD	TBD	-121	TBD	TBD
Channel Spacing	KHz	5000			5000	TBD	TBD
Receiver Bandwidth	KHz	3840	TBD	TBD	3840	TBD	TBD

Table 2

*Typical operator power levels for the UMTS pilot channel = max Input power (43 dBm) -10 dB = 33dBm as per UMTS defined testing procedures.

6.3 Antenna profiles used for modelling

There are three antenna types used in the compatibility study they are the

Terrestrial BTS profiles

Mobile Phone profiles

GSM onboard system profile

6.3.1 Terrestrial BTS profiles

The antenna gain and profile of antennas used in the studies that form the basis of this report differ depending on which modelling approach is carried out. The following sections highlight the antenna patterns and gains used for the Minimum Coupling Loss (MCL) and the SEAMCAT modelling approaches.

6.3.1.1 Terrestrial BS antenna characteristics used for MCL modelling

The study assumes a three sectored cell site with uniform gain in the horizontal plane:

- Antenna terrestrial BTS patterns used:
  - Vertical pattern defined by the ITU pattern ITU R F 1336 input parameters “2005 peak” version. The off-axis gain are calculated on the basis of a maximum antenna gain of 15 dBi (900 MHz) and 18 dBi (1800 MHz and 2 GHz).
  - Horizontal pattern: omni-directional in the horizontal plane within opening angle 120 degrees.
  - Downtilt angle: 0 degrees
- Terrestrial BTS Maximum Antenna gain used:
  - 15 dBi for GSM and UMTS 900 MHz,
  - 18 dBi for GSM and UMTS 1800 MHz
  - 18 dBi for UMTS 2GHZ

6.3.1.2 Terrestrial BS antenna characteristics used for SEAMCAT modelling

The study assumes a three sectored rural cell site assuming uniform gain in the horizontal plane:

- Antenna patterns:
  - Vertical patterns defined by ITU pattern ITU R F 1336 input parameters “2005 average” version. The off-axis gain are calculated on the basis of a maximum antenna gain of 15 dBi (900 MHz) and 18 dBi (1800 MHz and 2 GHz).
  - Horizontal pattern: Omni directional in the horizontal plane within opening angle 120 degrees.
  - Downtilt angle 2 degrees

- Maximum antenna gain used:
  - 15 - 1.7* = 13.3 dBi for GSM and UMTS 900 MHz,
  - 18 - 1.7* = 16.3 dBi for GSM and UMTS 1800 MHz
  - 18 - 1.7* = 16.3 dBi for UMTS 2GHZ

- Blocking response profiles
  - Not relevant due to scenarios being modelled.

*This value has to be confirmed. An explanation must be added later on.

6.3.2 Mobile antenna profiles

The study assumes an omni-directional antenna for all mobiles with a net 0 dBi gain:

- Antenna patterns used for both MCL and SEAMCAT modelling:
  - Vertical pattern: Omni directional in the vertical plane
  - Horizontal pattern: Omni directional in the horizontal plane

- Antenna gain used for both MCL and SEAMCAT modelling
  - 0dBi gain:

- Blocking response profiles
  - Not relevant due to scenarios being modelled.

6.3.3 Aircraft “antenna” profiles

Given that the length of the aircraft << distance to the ground, the aircraft is therefore assumed to behave as an omni-directional point source with zero net antenna gain..

6.4 Path loss parameters

There are two propagation path losses considered in the compatibility report, the path loss between the aircraft and the ground and the path loss between a terrestrial base station and a terrestrial mobile phone.

6.4.1 Propagation path loss between aircraft and victim receiver

Propagation model used between aircraft and the victim receiver is free space path loss with a standard deviation of 5 dB.

The free space path loss in dB is given by the formula:

$$L = 20 \cdot \log_{10} \frac{4\pi d}{\lambda}$$

Where:

- d is the distance between the transmitter and receiver;
- λ is the wavelength.

Or more conveniently:

$$L_{dB} = 92,4 + 20\log(D_{km}) + 20\log(F_{GHz})$$

Where D is the distance in Km and F the Frequency used in GHz.

6.4.2 Propagation path loss between terrestrial Base station and terrestrial mobile phone

The propagation model used between the terrestrial BTS and the terrestrial mobile was the extended Hata model defined in the SEAMCAT modelling tool.

6.4.3 Propagation path loss between aircraft Base station and aircraft mobile phone

The propagation model used between the aircraft BTS and the aircraft mobile is defined in section 7.2.2.

6.5 Interference modelling parameters for a Terrestrial network

The compatibility study focused on the interference limiting case based on the probability of interference in the rural cell environment. The rural cell radius was calculated via the SEAMCAT modelling tool based on the service availability and fading parameters.

	GSM-900		GSM-1800		UMTS	
	MS	BS	MS	BS	MS	BS

Cell Radius – Rural*	km	Determined by SEAMCAT using Availability = 95% Fading 5dB		Determined by SEAMCAT using Availability = 95% Fading 5dB		Determined via SEAMCAT	
Antenna Height	m	1.5	[30]	1.5	[30]	1.5	[30]

*Rural environment was used in the propagation model (Extended-Hata) since that it was considered that the most vulnerable cases are communication links that already are close to their limit of performance due to poor signal strength, and which are typically found in light-loaded systems where no internal interference (or interference from other sources) is present. For more details see section 7.

SEAMCAT analysis requires an interference modelling criteria to be defined. This criterion is different whether GSM TDMA or UMTS CDMA based technologies are used.

- o For GSM modelling the interference criteria used was: C/I+N = 9 dB
- o For CDMA based victim systems the interference criteria used SEAMCAT version 3 Link Level Data at a given frequency range.

6.6 Aircraft cabin environment

The aircraft cabin environment covers a number a parameters in order to simulate the effective EIRP of the aircraft seen from the ground. The three transmitting entities in the aircraft are, the NCU, the pico network and the onboard GSM mobiles.

- o The NCU: The maximum required EIRPs value of the NCU was calibrated from the worst case results from scenario 1 for each control frequency band (see section 5).
  - ▪ The NCU EIRP for GSM 900 and 1800 control = the necessary EIRP to equal the received ground system power level into aircraft at the window plus the system gain for GSM (0 dB).
  - ▪ The NCU EIRP for UMTS control = the necessary EIRP to equal the received ground system power level into aircraft at the window plus the system gain for UMTS (24 dB).

- o Pico network EIRP for GSM 1800 MHz connectivity = The NCU 1800 MHz EIRP value + 9 dB (minimum requirement for C/I for GSM voice service)

- o The onboard mobiles EIRP for GSM 1800 MHz = 0 dBm

The actual modelling approach for calculating the NCU EIRP from the received terrestrial BTS signals is defined in section 7.

The following additional parameters are used for the compatibility calculations.

Parameter	**Value**	**Unit**
Path loss model between ac-MS and ac-BTS	[TBD]	
Leaky cable EIRP characteristics	[TBD]	
NCU EIRP	TBD from Scenarios 1	dBm
BTS EIRP	9 dB + NCU EIRP value at 1800 MHz	dBm

6.7 Attenuation due to the aircraft

This parameter has been successively called hull attenuation, aircraft attenuation, and attenuation due to the fuselage, and a number of interpretations of the physical explanation and appropriate measurements have been discussed.
The proposed new naming is "Attenuation due to the aircraft" and this parameter aims to express the difference of propagation between:

- A transmitter (MS or BTS/NCU) situated in the air (at a given altitude) and a receiver situated on the ground,
- And a transmitter (ac-MS or ac-BTS/NCU) situated in an aircraft (at the same altitude) and a receiver situated on the ground.

Different measurements campaigns have been analysed and the figures are quite heterogeneous. However, the following starting values have been agreed within SE7:

- To an from an ac-MS : 5 dB,
- To and from an ac-BTS or NCU using a radiating cable type of antenna : 15 dB

Those figures are assumed to be conservative (i.e. low) and the calculations shall include a sensitivity analysis so showing the effect of decrease to even lower values.

6.8 Aircraft Positioning

The following parameters were used to reflect the dynamism of the airborne system:

- Single aircraft moving at cruise
- Single aircraft moving to/from airport
- Multiple aircraft moving at cruise (number of aircraft with system onboard)
- Multiple aircraft moving to/from airport (number of aircraft with system onboard)

Parameter	**Value**	**Unit**
Aircraft start height (above ground) with system on	[3,000]	Metres
Aircraft cruise altitude (above sea)	[Between 9 – 12,000]	Metres
Aircraft speed at cruise	[880]	Km/hr
Max speed at 3,000 metres	450	Km/hr
Aircraft rate of incline / decline	[700-1,000]	Metres/minute
Permitted horizontal distance between aircraft at cruise	[10]	Minutes
Permitted vertical distance between aircraft at cruise	[700]	Metres
Permitted horizontal distance between aircraft approaching airport	[2]	Minutes
Permitted vertical distance between aircraft approaching airport	[700]	Metres

The actual modelling approach for calculating the effects of various aircraft positions are defined in section 7.

7 MODELLING TECHNIQUES

In this chapter the methodology used to represent the different systems and events under study are described. This includes the basic considerations on what and how to model, and more detailed information on the parameter definition used for the simulations. SE7 has used two main methods for describing the risk of interference from GSM onboard aircraft: manual Minimum Coupling Loss (MCL) calculations and automatic calculations by the ERO-developed SEAMCAT tool. A decision to use the SEAMCAT tool was taken at an early stage due to its availability and history, but this choice also caused some restrictions on the modelling.

7.1 Terrestrial network modelling

The challenge of any modelling is to get a representation of real life that is sufficiently accurate to illustrate the effects under consideration. The approach taken when modelling the terrestrial network in order to assess the possible interference is to use a priori knowledge of the most vulnerable parts of networks and communication situations. It is of little interest to convey detailed studies of cases not representing any challenge. Early investigation indicated that the signal levels that can be expected on ground from GSM onboard systems are likely to be around the thermal noise floor of the receivers at maximum.

Independent of the type of terrestrial system (being GSM or UMTS), the most vulnerable cases are communication links that already are close to the limit of performance due to poor signal strength. These are typically found in light-loaded systems where no internal interference (or interference from other sources) is present. In more heavy loaded networks the performance of a link is already influenced by interference (i.e. the noise floor is higher) so the effect of an additional interfering signal of a certain value is less. A network designed for coverage and a more relaxed availability is therefore more vulnerable for external interference than a high-quality network with large capacity when measuring the probability of interference for an arbitrary connection.

In real life the network operators and system manufacturers are using different methods of increasing the performance of the system compared to the minimum level defined in the specifications. In its work, SE7 has made large efforts in order to reflect the real implementations.

7.1.1 GSM modelling

A single cell approach is used to represent the terrestrial GSM network. By studying the effect on a pure noise-limited cell and not taking into account possible handovers, the most vulnerable case is captured. For MCL calculations this simply means that the highest BTS output power, the lowest receiver noise figure (both for BTS and MS), and the maximum side lobe levels of the reference antenna are used. When considering the results, possible simultaneous interference from the same sources on several cells are discussed. In this way the total effect on a terrestrial network may be estimated.

An MCL calculation is used to determine the highest signal value from a terrestrial cell received by a mobile inside the aircraft at a certain height (Scenario 1). This level is then used to calculate the needed power of both the onboard NCU and BTS to be used in Scenarios 3 and 4.

MCL calculations are also used to illustrate the maximum increase of noise floor in a terrestrial receiver as result of interference from one aircraft in the worst-case position in addition to the SEAMCAT simulations of Scenarios 3 and 5.

SEAMCAT v.2.1.0 simulations are used to illustrate the typical influence in a vulnerable cell. For GSM, the influence of the interference is quantified by the parameter C/(I+N), i.e. the probability that the C/(I+N) exceeds a limit. By selecting a certain availability target for the cell, the SEAMCAT tool simulates terrestrial links with a distribution of received signal strength reflecting the defined availability. (High availability: less number of vulnerable links). It then calculates the effect of one or more interfering links on each of the victim links and every signal calculation is stored in an array. It is then possible to calculate different statistical parameters based on the data.

7.1.1.1 SEAMCAT modelling of GSM

The power level of the interfering signal from aircraft is so low that it is considered sufficient to study only co-channel interference. Referring to the Scenarios defined in chapter 5, the following situations are modelled:

1. a) (Scenario 5) One mobile station (ac-MS) inside an aircraft using the same channel as a noise-limited terrestrial base station (g-BTS), the aircraft being positioned within the "sight" of the g-BTS antenna.
   b) (Scenario 6) A number of ac-MS (one per aircraft) using the same channel, and the number of aircraft being positioned within the "sight" of the g-BTS antenna.
2. a) (Scenario 3) One base station (ac-BTS) inside an aircraft using the same channel as a noise-limited mobile station on ground(g-MS), the aircraft being positioned within the sight of the g-MS
   b) (Scenario 4) A number of ac-BTS (one per aircraft) using the same channel, the aircraft being positioned within the sight of the g-MS
3. a) (Scenario 3) One NCU inside an aircraft, the aircraft being positioned within sight of a terrestrial noise-limited mobile station.
   b) (Scenario 4) A number of NCU's (one per aircraft), the aircraft being positioned within the sight of the g-MS.

   Situation 1 and 2 is simulated only for the connectivity band, i.e. 1800 MHZ, while situation 3 also includes the 900 MHz GSM band.

Reference is made to the SEAMCAT documentation for more detailed description of the design and parameter use of the tool.

The detailed parameter settings of SEAMCAT are shown in APPENDIX XX.

7.1.1.1.1 Scenario 5 and 6, Situation 1):) Modelling a BTS in a terrestrial noise-limited GSM cell

In this situation the Victim Link is the link between an arbitrary g-MS and the g-BTS, i.e the g-MS is the "Wanted Transmitter" and the g-BTS is the "Victim Receiver". Further the Interfering link is the link between a mobile inside an aircraft cabin (ac-MS) and the ac-BTS. The ac-MS is the "Interfering Transmitter" and the ac-BTS is the "Wanted Transmitter".

The target of the modelling is to reflect the typical situation where the g-BTS is connected to a sectorial antenna with 120° horizontal 3dB opening angle; hence both the g-MS connected to the g-BTS and aircraft with potential interfering transmitters are within the same horizontal opening angle when seen from the g-BTS. The sector-antenna pattern is typically described through its horizontal and vertical pattern, possible downtilt and the maximum gain.

The inherent SEAMCAT design makes some compromises necessary in order to get a realistic model. Especially it is difficult to model a horizontal sector and ensure that both the wanted transmitters and the interfering transmitters are within that sector, and still with random direction and distance. It was therefore decided to disregard the real horizontal variations of antenna pattern, and use an average value for the maximum gain instead. Hence in the modelling the theoretical cell may as well be circular with no variations of the antenna gain in the horizontal direction. In this way random horizontal angles may be used for all positioning of entities.

As already mentioned, the noise-limited case is the one of interest. SEAMCAT has a mode of operation where the terrestrial cell size is defined by certain input parameters for a noise-limited network. The maximum distance to the interferer (the aircraft) is set manually. In Scenario 3 and 4 where the Victim receiver is a g-BTS, the maximum distance for SEAMCAT simulations is set to 150 km, corresponding to an elevation angle of sight of around 4 degrees seen from the BTS for aircraft at 10000m height.

When defining the number of aircraft that may be potential interfering transmitters in Scenario 6, the sector of 120 degrees and a maximum distance of 150km is considered. Then this number has to be multiplied by the probability that a mobile in every aircraft is using exactly the same channel, in order to get an assessment of the probability for a certain interference level to occur.

7.1.1.1.2 Scenario 3 and 4, Situation 2) Modelling a noise-limited MS receiving interfering signals from ac-BTS

In this situation the Victim Link is an arbitrary link between a g-BTS and the g-MS, i.e. the g-BTS is the "Wanted Transmitter" and the g-MS is the "Victim Receiver". Further the Interfering link is the link between a BTS inside an aircraft cabin (ac-BTS) and an in-cabin mobile (ac-MS). The ac-BTS is the "Interfering Transmitter" and the ac-MS is the "Wanted Transmitter".

The real situation here is a mobile station in a cell with no terrestrial interference present. The worst-case situation is then when the mobile is in an outdoor environment with poor signal strength from the g-BTS,. Since the antenna of the mobile station is omnidirectional, the direction towards the g-BTS is of no significance, neither is the direction towards the interference source. Therefore random horizontal angle settings can be used both for g-BTS antenna pointing and the link path directions in SEAMCAT. As for Scenarios 5 and 6, the automatic noise-limited system is used for the terrestrial link, hence providing the appropriate distribution of received wanted signal strength for the Victim receiver. In this situation, the maximum distance to the Interfering transmitter can be reduced; due to two reasons: In the general case the mobile station is normally seeing much less of the sky towards the horizon, and more important since no antenna gain is present the longer distance to aircraft at lower elevation angles rapidly reduces the received power of the interfering signal. A maximum distance of 50 km is used; at that distance the free space loss at 1800MHz is more than 130 dB giving a received power from the ac-BTS far below the noise floor of the mobile receiver.

Similar reflections considering the number of multiple interferers for Scenario 4 may be done as for Scenario 6 described above. For multiple interference sources of the same kind to be present; the different aircraft must use the same frequency for their connectivity component. However, in this case other aircraft may contribute by transmissions from the NCU. Situation 2 and 3 must therefore be considered together for both Scenario 3 and 4.

7.1.1.1.3 Scenario 3 and 4, Situation 3) Modelling a noise-limited MS receiving interfering signals from NCU

This case is very close to situation 2) of the same Scenarios, the only difference is that the Interfering transmitter is the NCU instead of the ac-BTS. The difference is that the power level of the Interfering transmitter is at least 9 dB lower, and that this situation applies to each channel in every band under control by the NCU.

In contrast to the earlier described situations, now the number of interference sources equals the number of equipped aircraft estimated within sight, since the NCU transmission is active whenever the service is activated.

7.1.2 UMTS modelling

The use of CDMA for distinguishing between channels or connections in UMTS makes a huge difference from GSM. First of all it is less meaningful to speak about a pure noise-limited system, since by nature a number of users are sharing the same frequency channel, hence a CDMA system always has intrinsic interference. In practice one may however consider a light-loaded CDMA system as noise-limited when the number of users is so small that the resulting rise of noise floor in the receiver is negligible. It therefore makes sense also for UMTS to compare the power of the interfering signal with the thermal noise floor of the victim receivers, and consider the possible rise of that noise floor as an indication of the consequence of the interference.

Just as for the GSM-case, manual MCL calculations of Scenario 1 are used to assess the maximum power levels received by an in-cabin mobile at different heights and in different frequency bands. These levels are then used for defining the output power levels of the NCU at different bands. MCL calculations further show worst-case values for received levels by terrestrial mobiles as a result of NCU transmissions for Scenario 3.

But unlike the GSM-case, the effect of the whole network is not easily deduced from a study of an "isolated" noise-limited cell for UMTS. Soft handovers, traffic-dependent coverage and other issues make the picture much more complicated. Therefore a model of a larger portion of a typical network must be considered in order to give a better indication on the potential influence of the interfering signals.

7.1.2.1 UMTS modelling in SEAMCAT

Simulating CDMA systems is only possible in SEAMCAT v.3.

The principle used when simulating an UMTS network, is to reflect the status of a target cell and 18 surrounding cells in all details, and in addition also make some assumptions on the cells or border further away. All communication links within the cells are calculated and a certain mobility factor is assumed. The effect of external interference is then given in terms of capacity reduction instead of a value for C/I or C/(I+N). In this way the effect is more directly stated than for the GSM simulations, where an interpretation of the given probability by reduced quality must be estimated.

For UMTS only one situation has to be simulated corresponding to Scenarios 3 and 4: one or several aircraft equipped with NCU of a certain output power within sight of the UMTS mobile-stations (g-UE). Similar considerations as for the NCUs in the GSMbands are made for multiple interferers.

7.2 Multiple aircraft modelling

Different approaches may be taken when modelling one or several aircraft at different heights. It is worthwhile to mention that the Monte Carlo simulation approach of SEAMCAT is more a collection of snapshots from different typical situations than real simulations trying to emulate a real system. Considering this, it is of less importance to model the movement of aircraft at a detailed level, as long as the number and distribution of aircraft in the snapshots are realistic. Effort has therefore been put on estimating a realistic number of aircraft being within sight of the victim receiver being investigated.

As mentioned in earlier paragraphs the relationship between the number of aircraft and the number of actual interferers on one channel is depending on the situation:

- For Scenario 6: Uplink interference from ac-MS in multiple aircraft

P (interference in g-BTS) = [Seamcat-calculated-value for X interferers] x P(a mobile is active) x P(the same channel is used)

- For Scenario 4: Downlink interference from ac-BTS

P(interference in g-MS) = [Seamcat-calculated-value for X interferers] x P(the same channel is used)

- and for Scenario 4: Downlink interference from NCU:

P(interference in g-MS) = [Seamcat-calculated-value for X interferers]

7.2.1 Aircraft distribution modeling

As an input to determine the maximum number of potential interferersfor Scenarios 4 and 6, snapshots from radar surveillance of the London area in busy air traffic hours are considered. The worst case snapshot showed that 146 planes were airborne at a height above 3000m within a radius of 98 km around Heathrow. The distribution is shown in the following table:

Altitude	Percentage
3000 - 4000	25 %
4000 - 5000	12 %
5000 - 6000	11 %

6000 - 7000	8 %
7000 - 8000	6 %
8000 - 9000	9 %
9000 - 10000	11 %
10000 - 11000	8 %
11000+	10 %
Total	100 %

In addition the effect of a number of interferers fixed at a certain height has been investigated, based on the following maximum number of aircraft within sight of a victim receiver (based on the maximum distance to the interferer and the opening angle of the receiver antenna)

Receiver type:	Max .number at 3000m	Max .number at 5000m	Max .number at 8000m	Max .number at 10000m
g-BTS	[TBD]	[TBD]	[TBD]	[TBD]
g-MS	[TBD]	[TBD]	[TBD]	[TBD]

7.2.2 Modelling of the airborne system

In order to perform both manual MCL calculations and SEAMCAT simulations, the three different transmitting sources of the airborne system must be modelled. For SEAMCAT simulations it is the combination of the transmitters themselves and their local environment (the aircraft fuselage) that together must be modelled as a transmitting source.

7.2.2.1 The ac-MS

When observed from a distance (a receiver on ground) the transmissions from an ac-MS is simply modelled as the real EIRP of the transmitter, reduced by the attenuation of the aircraft fuselage. Although the actual value of this attenuation varies both due to geometry and different structures of different aircraft, an average value of 5 dB has been used in the calculations. However a sensitivity analysis showing the effect of values down to 2 dB is also included. The EIRP of the ac-MS will be effectively limited to 0 dBm, this is assumed to be sufficient to ensure connectivity to the ac-BTS.

7.2.2.2 The ac-BTS and the NCU

Both the ac-BTS and the NCU power (and EIRP) will depend upon the aircraft size and the minimum distance at which the system is designed to operate. A lower height obviously requires more power to ensure the required S/N compared to the terrestrial signals, but on the other hand higher power also increases the risk of interference. It is therefore no surprise that the risk of interference rapidly decreases if the minimum operative height is increased.

The current design of the system from potential operators suggests that one or two parallel radiating cables are used as antenna solution for the NCU and the ac-BTS.

Assessing the real EIRP of the ac-BTS and the NCU signals through a radiating cable inside an aircraft cabin is not an easy task, and more work and measurements have to be performed in order to ensure correct calculations.

In the meantime a rather simple model is used, which is believed to be sufficiently correct to provide indicative values.

The model consists of two steps:

1) Decide the total power needed inside the cabin in order to ensure that all mobiles receive the required level

2) Consider the attenuation effect of the aircraft body on this total power

As for the MS-case, the combination of these two steps gives an estimate of the equivalent EIRP of the ac-BTS or NCU inside the aircraft when observed as a point source in the sky.

Step 1: Assessment of the total power inside the cabin:

In the model we consider the aircraft fuselage to be a cylinder with the radius R and length L corresponding approximately to the real values (the body is not a real cylinder). We start with the field strength required at the cylinder surface (i.e. the power received by a mobile close to the fuselage window or wall), this is denoted $P_{Target.}$ We then want to calculate the total power needed to cover the whole cabin, i.e. the surface of the cylinder in the model, $P_{cylinder.}$ Further we define the difference between these two levels as the “Radiating Factor”.

It is assumed that the onboard transmitter (NCU or ac-BTS) is able to set up a near uniform field over the side area of the cylinder, i.e. a uniform power level measured just inside the "skin" of the aircraft. Although we assume that this field must come from a source along the centre line of the cylinder, the model do not consider the peculiarities inside the cylinder, it only assumes that the power is radiated from the side area of he cylinder.

In the ideal case with a uniform distribution of the field, the total power of the field inside the aircraft is then the power/m^2 multiplied with the side area of the cylinder.

The power/m2 is calculated from the target power value to be achieved at the cylinder and the corresponding dipole area for the actual frequency.

The dipole and cylinder areas are given by the formulas:

$$A_{dipole} = 3\lambda^2/8\pi$$

$$A_{cylinder\text{-}side} = \pi DL$$

where λ is the actual wavelength, D is the diameter and L is the length of the cylinder

Hence we get an equation for the minimum total required power inside the cabins:

$$P_{cylinder\text{-}minimum} = P_{Target} (\pi DL) / (3\lambda^2/8\pi)$$

- where P_{Target} is the required Rxlev measured by a mobile close to the aircraft skin.

In order to better reflect the real environment, a corrective margin has to be added. This margin covers fading effects, reduction of radiating cable power along the cabin and other inaccuracies.Expressed in dB and including this margin gives the following equation for the total power needed inside the cabin:

$$P_{cylinder} = P_{cylinder\text{-}minimum} + M = P_{Target} + 10 \log (\text{Cylinder Side Area}) – 10 \log(A_{dipole}) + M$$

The Radiation factor defined by the difference between the two power levels is then

Radiation-factor = $P_{cylinder} - P_{Target}$ = 10 log (Cylinder Side Area) – 10 log(A_{dipole}) + M

By using 4 m diameter and 30 m length for a small passenger aircraft, 7 m diameter and 50 m length for a large, and 15 dB as the margin M, the following values are obtained for the Radiation factor:

Frequency	SMALL aircraft		LARGE aircraft	
	Without margin	Margin included	Without margin	Margin included
900 MHz	44,5 dB	**60 dB**	49,2 dB	**64 dB**
1800 MHz	50,6 dB	**66 dB**	55,2 dB	**70 dB**
2000 MHz	51,5 dB	**67 dB**	56,1 dB	**71 dB**

Step 2: Attenuation of the aircraft fuselage

As described in step 1, we assume that the total power is distributed over the surface of a cylinder inside the cabin. The fuselage is a combination of reflecting surfaces and surfaces where the radiation may penetrate. The main source of radiation out of the fuselage is the windows. Comparing the area of windows to the complete cylinder area indicates that the main part of the distributed power will be reflected and eventually absorbed within the aircraft, it is only a fraction that hits the windows and has a chance to escape.

In lack of sufficient measurements, a range of 5 to 15 dB for the aircraft attenuation is used for signals to and from the radiating cable, e.g. the transmitted signals from the ac-BTS and NCU causing potential interference in ground mobiles.

Hence we get the final equation for the equivalent EIRP of ac-BTS or NCU for Scenario 3 and 4 as follows:

P_{EIRP}=$P_{cylinder}$ - Aircraft attenuation = P_{target} + Radiation Factor – Aircraft attenuation

The actual P_{target} is calculated by the following equations for the NCU and ac-BTS respectively:

$P_{target\text{-}NCU}$ = Maximum-Rxlev from terrestrial network* + Shielding margin (0 dB for GSM, 24 for UMTS)

$P_{target\text{-}ac\text{-}BTS}$ = $P_{target\text{-}NCU}$ + 9 dB

* One value for GSM 900, GSM 1800 and UMTS/UTRA 2 GHz

An alternative description used in illustrative MCL calculations

In addition to the described theoretical model giving values for the equivalent EIRP of the ac-BTS and NCU inside an aircraft to be used for the SEAMCAT simulations of Scenarios 3 and 4, a more implementation-related description is included and used in example link budgets shown in annex xx . In this example a number of assumptions on the radiating cable parameters and its installation are used together with a theoretical model for the short-distance and long-distance propagation between a radiating cable and a mobile. The theoretical background of the equations used is shown in annex xy.

7.2.3 Multiple Interference Margin (MIM)

Co-editors note : This subject is proposed to be included in the other paragraphs

7.2.3.1 Control device

Editors note: This sub section shall contain the relevant information to obtain the MIM for the NCU

7.2.3.2 Connectivity part (GSM 1800 MHz)

Editors note: This sub section shall contain the relevant information to obtain the MIM for the GSM connectivity part operating in the 1800 MHz range

7.3 Interference modelling techniques

Editors note: This section describes which the modelling approaches used for the compatibility analysis and the results of the modelling.

When quantifying the potential interference by giving a certain value or a distribution function for any parameter, it is important that the assumptions and conditions are stated together with the information.

In its work SE7 has produced results in at least 3 categories:

A. MCL calculations typically give worst-case figures, i.e. the nominal (mean) power values of the interference in the worst geometry for the aircraft-victim receiver, and on the limit conditions for the victim link. The result is typically given as “Increase of noise floor compared to thermal case”.

B. simulation of representative air traffic (e.g. speed, altitude and density) typically gives estimates of probability for interference level exceeding a chosen limit. This type of figures gives an indication of how often disturbance may occur, but since they assume that the terrestrial link is of the most vulnerable type (the interference level is compared to the thermal noise floor) we are still dealing with worst-case considerations. Results of this category may be obtained from SEAMCAT by choosing I/N or (N+I)/N as interference criteria.
C. applying a representative distribution of terrestrial network conditions gives estimates on the real experienced level of interference or disturbance, since it combines the probability of interfering signals above a certain limit, and the probability that the victim link are sufficiently vulnerable. Results of this category are obtained from SEAMCAT by using the C/(N+I) criteria.

Descriptions of category A and B are general and not dependent on the actual network layout, the current traffic or the service types supported. Hence such figures are applicable everywhere and should not be controversial, however they do not really quantify the potential problem. There could e.g. be cases where a relatively high probability for a certain I/N to be exceeded would not be detectable at all due to self-generated interference already present, while in other cases the same I/N distribution may cause a severe degradation.

Category C is avoiding this uncertainty, provided that the reference terrestrial network can be agreed as representative. In fact, if the situation described for category A and B is true, it means that there are large differences between the terrestrial networks, and hence it could be similar difficulties to agree on typical reference values.

It is only the Regulatory Authorities that are in position to define limits on what could be accepted and what should not in this field. It seems natural that the limit will be of the form maximum tolerated aggregated interfering power with a certain probability label.

8 MODELLING RESULTS

8.1 *Results of scenario 1*

The first scenario (downlink) aims to assess the possibility for an ac-MS/ac-UE to receive a signal from a g-BTS/g-NodeB. The results are expressed with a difference between the signal received by the ac-MS/ac-UE and the sensitivity of this ac-MS/ac-UE.

For each altitude, the margin dedicated to the worst case elevation angle has been mentioned. [The worst case elevation angle at 900 MHz is 5° whereas it is 48° at 1800 MHz and 2 GHz.]

Altitude		900 MHz (GSM)		1800 MHz (GSM)		2 GHz	
		Standard Values	Operator Values	Standard Values	Operator Values	Standard Values	Operator Values
3	km	-28,54	-31,54	-20,34	-23,34	-24,42	-26,42
4	km	-26,12	-29,12	-19,44	-22,44	-22,20	-24,20
5	km	-24,26	-27,26	-18,47	-21,47	-20,57	-22,57
6	km	-22,75	-25,75	-17,67	-20,67	-19,27	-21,27
7	km	-21,49	-24,49	-17,00	-20,00	-18,19	-20,19
8	km	-20,40	-23,40	-16,42	-19,42	-17,27	-19,27
9	km	-19,47	-22,47	-15,91	-18,91	-16,47	-18,47
10	km	-18,65	-21,65	-15,45	-18,45	-15,77	-17,77

The margins contained in the tables are the differences between the signal levels received by the ac-MS/ac-UE and their sensitivity. A negative margin shows the additional isolation which is needed to screen the terrestrial networks.

Some additional information can be found in annex A.

Given the parameters used and these results, there is visibility of the terrestrial networks in the aircraft.

8.2 *Results of scenario 2*

The second scenario (uplink) has been designed to assess the ability of an ac-MS/ac-UE to successfully access a ground network.

For each altitude, the margin dedicated to the worst case elevation angle has been mentioned. [The worst case elevation angle at 900 MHz is 5° whereas it is 48° at 1800 MHz and 2 GHz].

Altitude		900 MHz (GSM)		1800 MHz (GSM)		2 GHz	
		Standard Values	Operator Values	Standard Values	Operator Values	Standard Values	Operator Values
3	km	-20,54	-24,54	-9,34	-13,34	-16,42	-17,42
4	km	-18,12	-22,12	-7,12	-11,12	-14,20	-15,20
5	km	-16,26	-20,26	-5,49	-9,49	-12,57	-13,57
6	km	-14,75	-18,75	-4,18	-8,18	-11,27	-12,27
7	km	-13,49	-17,49	-3,10	-7,10	-10,19	-11,19
8	km	-12,40	-16,40	-2,18	-6,18	-9,27	-10,27
9	km	-11,47	-15,47	-1,39	-5,39	-8,47	-9,47
10	km	-10,65	-14,65	-0,68	-4,68	-7,77	-8,77

The margins contained in the tables are the differences between the signal levels received by the g-BTS/g-NodeB and their sensitivity. A negative margin shows the additional isolation which is needed to screen the terrestrial networks.

Some additional information can be found in annex A.

Given the parameters used and these results, an ac-MS/ac-UE is able to connect a ground network.

8.3 Results of scenario 3

TBC

8.4 Results of scenario 4

TBC

8.5 Results of scenario 5

TBC

8.6 Results of scenario 6

TBC

9 OTHERS MITIGATION FACTORS AND TECHNIQUES

Editors note: This section highlights the mitigation factors of the system and their implication on the results and observations made in the previous sections.

The NCU has been widely developed and modelled in the previous chapters of this report. Others factors and techniques can be taken into account in order to provide a bigger margin between terrestrial and onboard networks or in order to be mixed up with the NCU so as to reduce the transmission level of the NCU.

9.1 Mitigation factors

Editor's note: A number of mitigation factors will be examined in the final draft ECC report, e.g.:

- Voice activity factor
- Doppler effect
- Depolarization loss

9.2 Mitigation techniques

Editors note: A number of mitigation techniques will be examined in the final draft ECC report, e.g.:

- Frequency hopping
- Minimum altitude of the aircraft to switch the transmission of the system on
- Determination of zones inside the aircraft, in which the communications are authorized

10 OBSERVATIONS

Editors note: This section highlights the observations of the results shown in the previous section.

11 CONCLUSIONS

Editors note: This section provides the final conclusions and recommendations of the study.

12 BIBLIOGRAPHY

Editors note: This section will include references to the sources used in obtaining data for the study.

ANNEX A : Complete simulations results related to scenarios 1 and 2

As a complement of section 8.1 and 8.2, the following sets of curves are the complete simulation results.

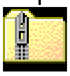
The first scenario (downlink) aims to assess the possibility for a ac-MS/ac-UE to receive a signal from a g-BTS/g-NodeB. The results are an estimation of the level of emission of the NCU, so that a ground network should be screened in a plane.

The second scenario (uplink) has been designed to assess the ability of an ac-MS/ac-UE to successfully communicate to the ground network.

For each set of curves shown below :

- If the margin is >0, it means that there is enough isolation for the Terrestrial network and the onboard network to be screened,
- If the margin is <0, it means that an extra isolation is necessary for the two parts to be screened.

The complete Excel sheets can be found in the document SE7(05)126 Rev3.



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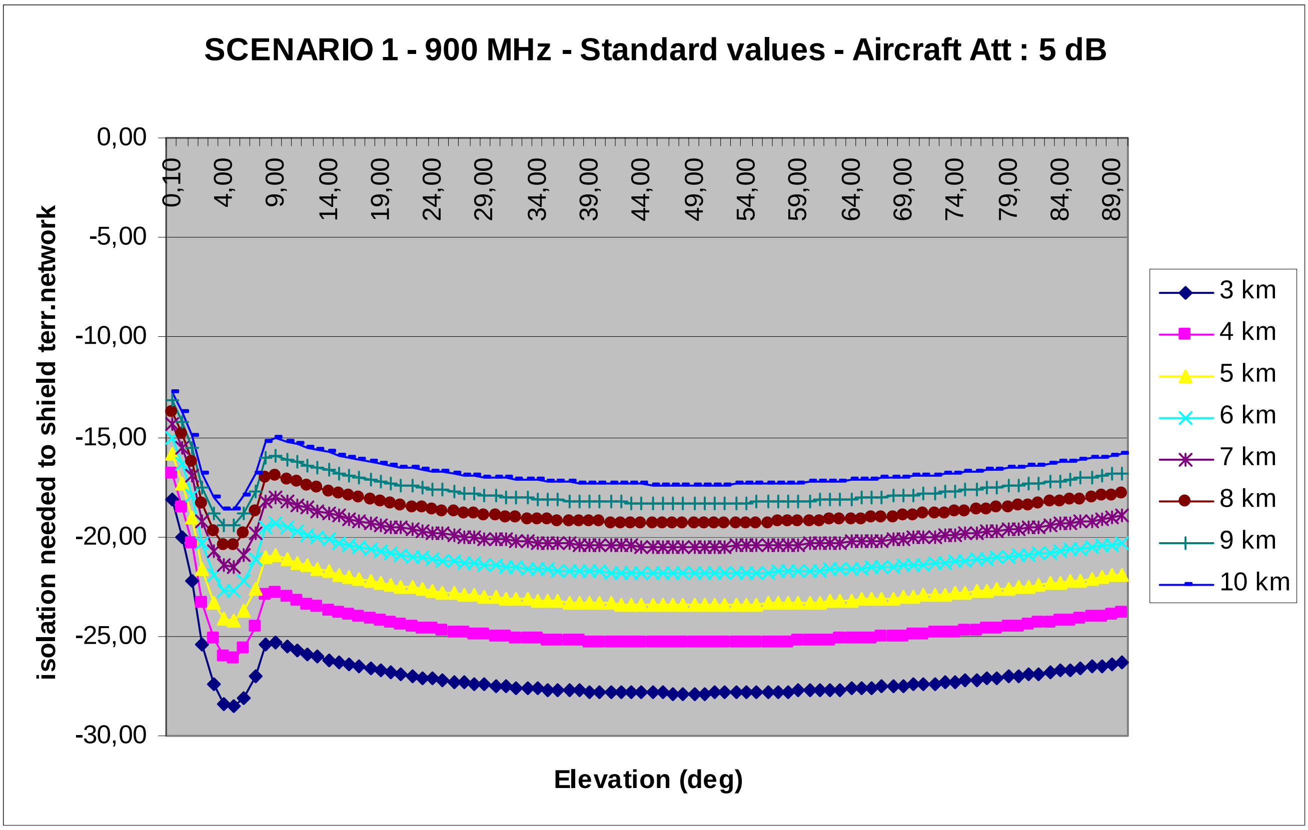
Here are the main parameters and principles used for the calculations:

- Aircraft attenuation : 5 dB (the effect of changing this value is a simple translation on the curves)
- Systems/Frequencies considered : GSM 900, GSM1800, UMTS 2 GHz
- Calculation of the distance ground/aircraft : curvation of the earth (radius = 6378 km)
- Downtilt of g-BTS/g-NodeB antenna : 0°
- g-BTS/g-NodeB antenna pattern : Rec. ITU-R F.1336-2
- ground/aircraft propagation model : Free space loss
- Emission/Reception parameters: see section 6.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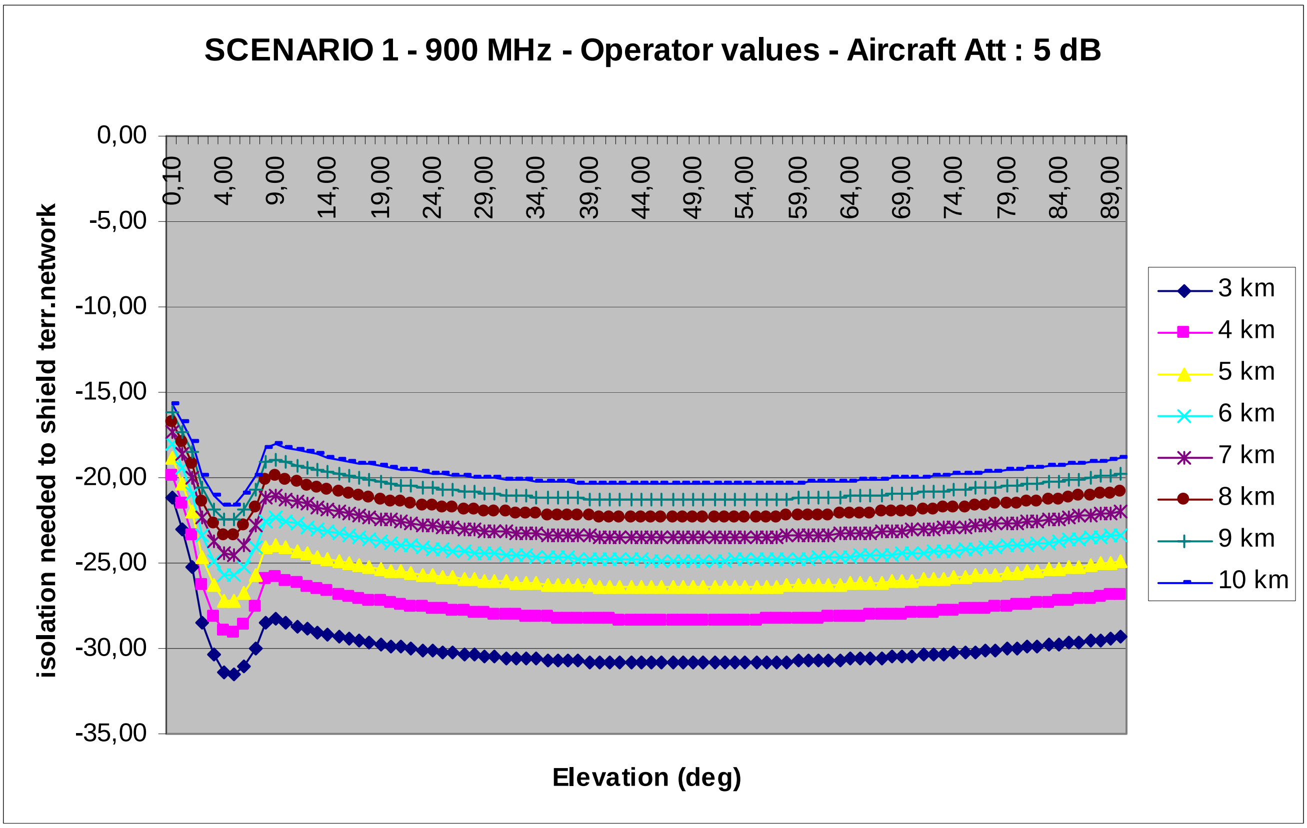
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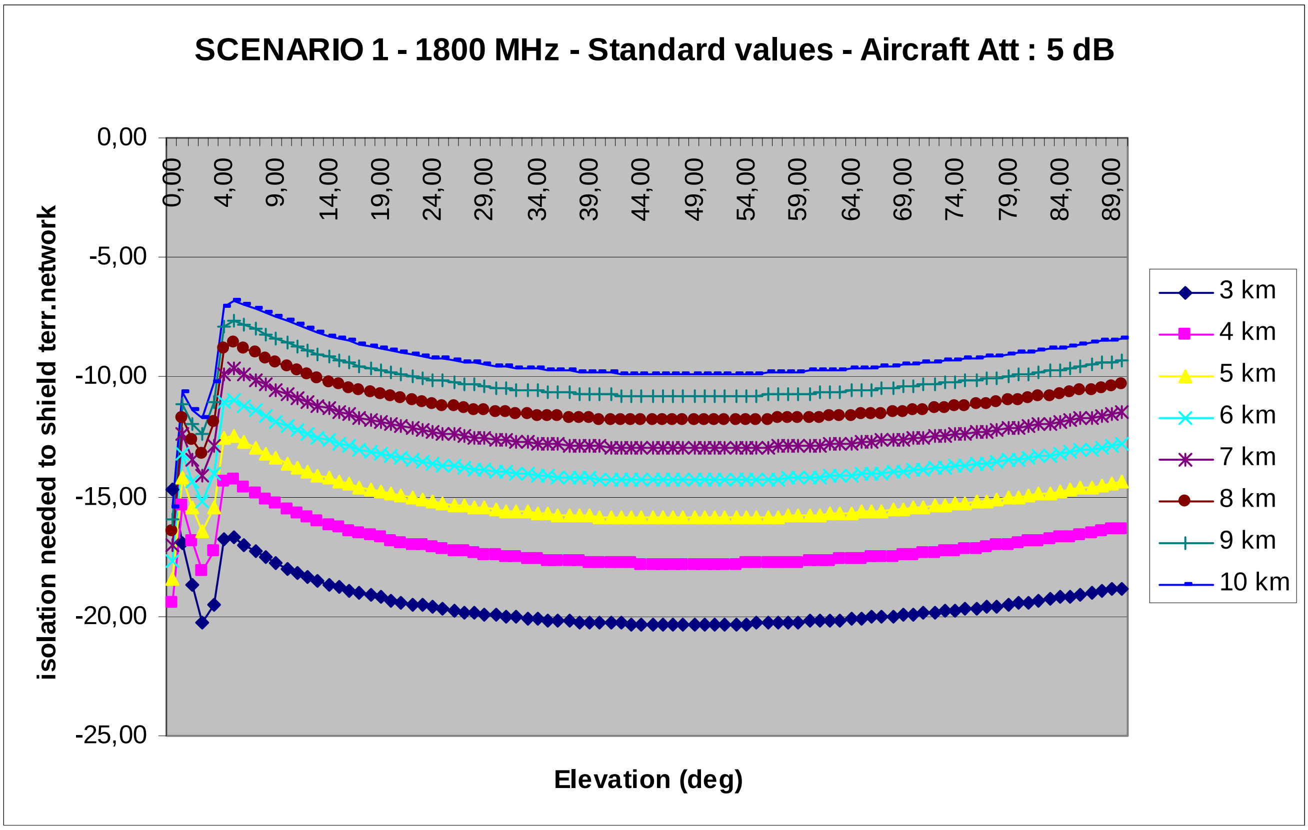
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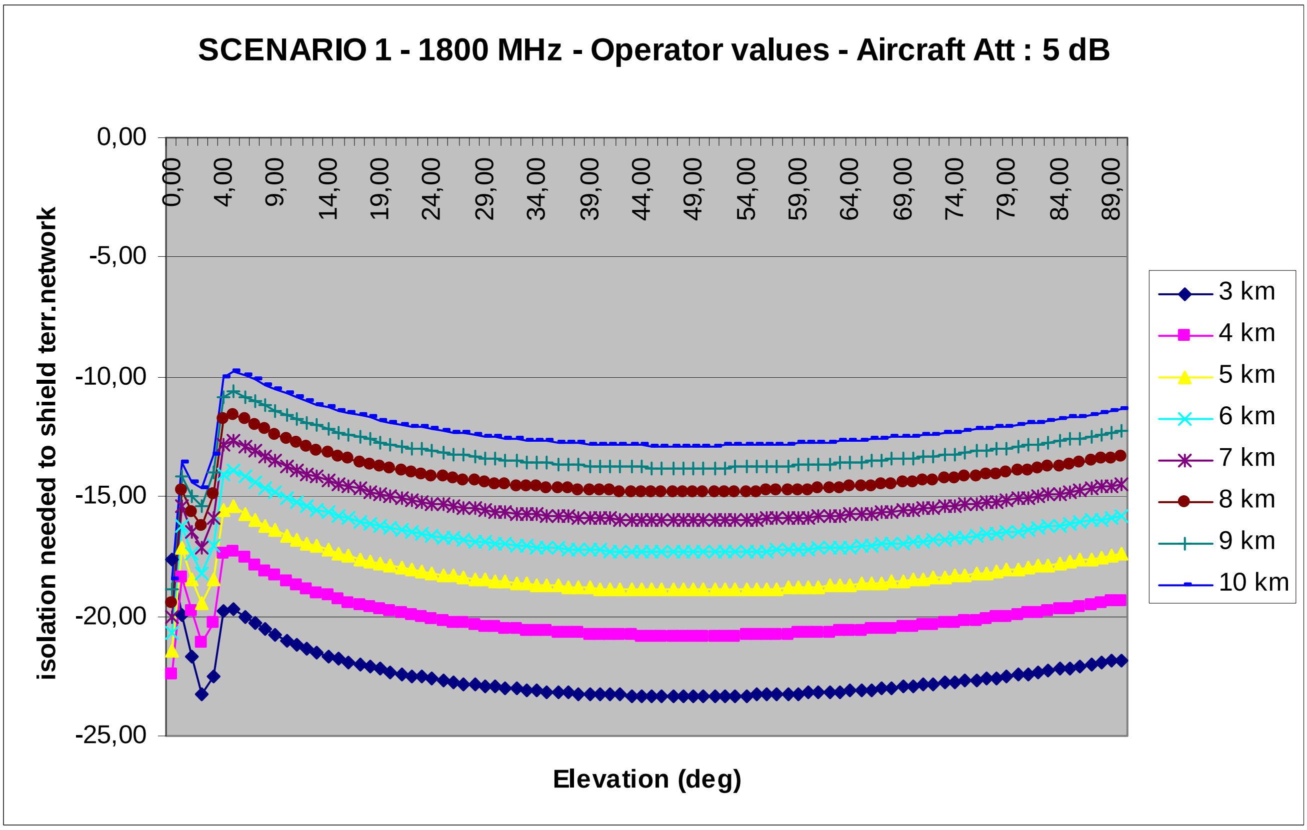
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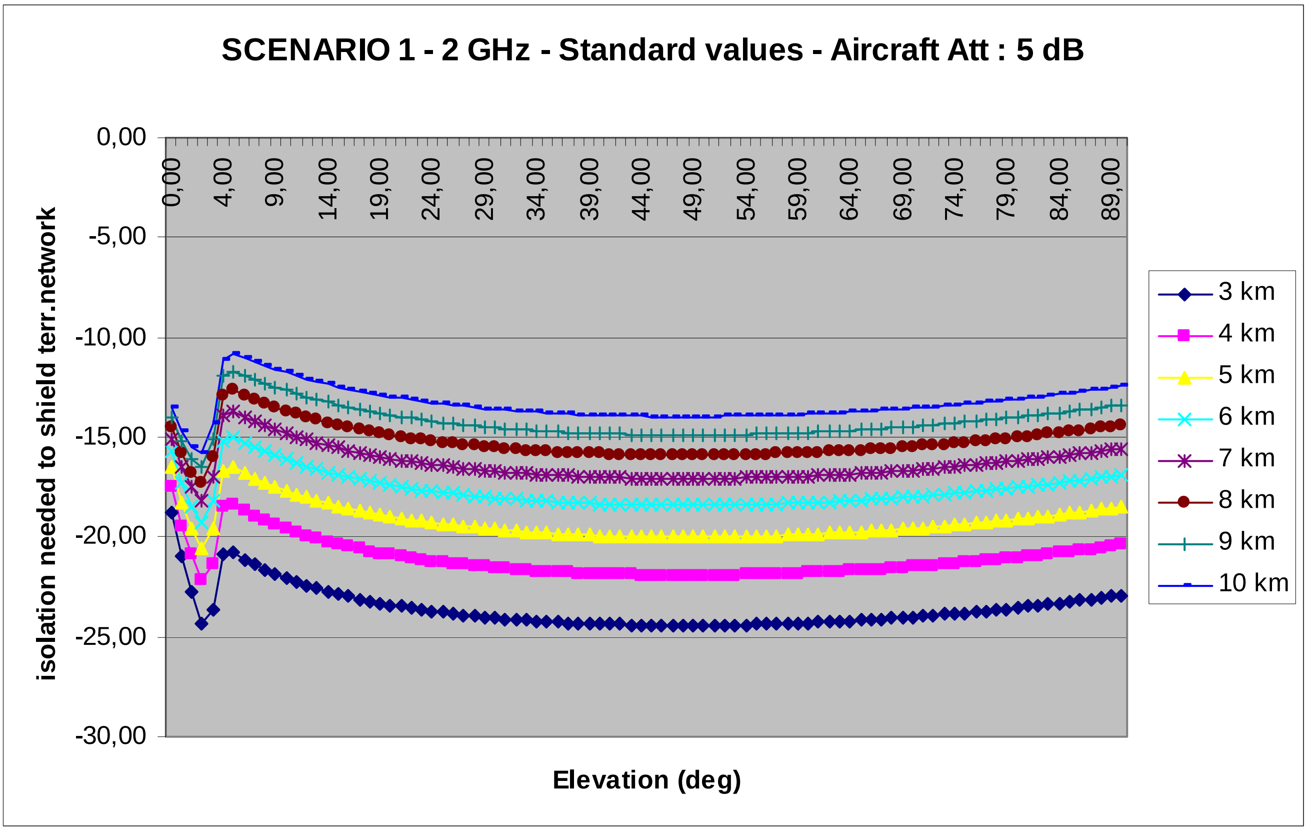
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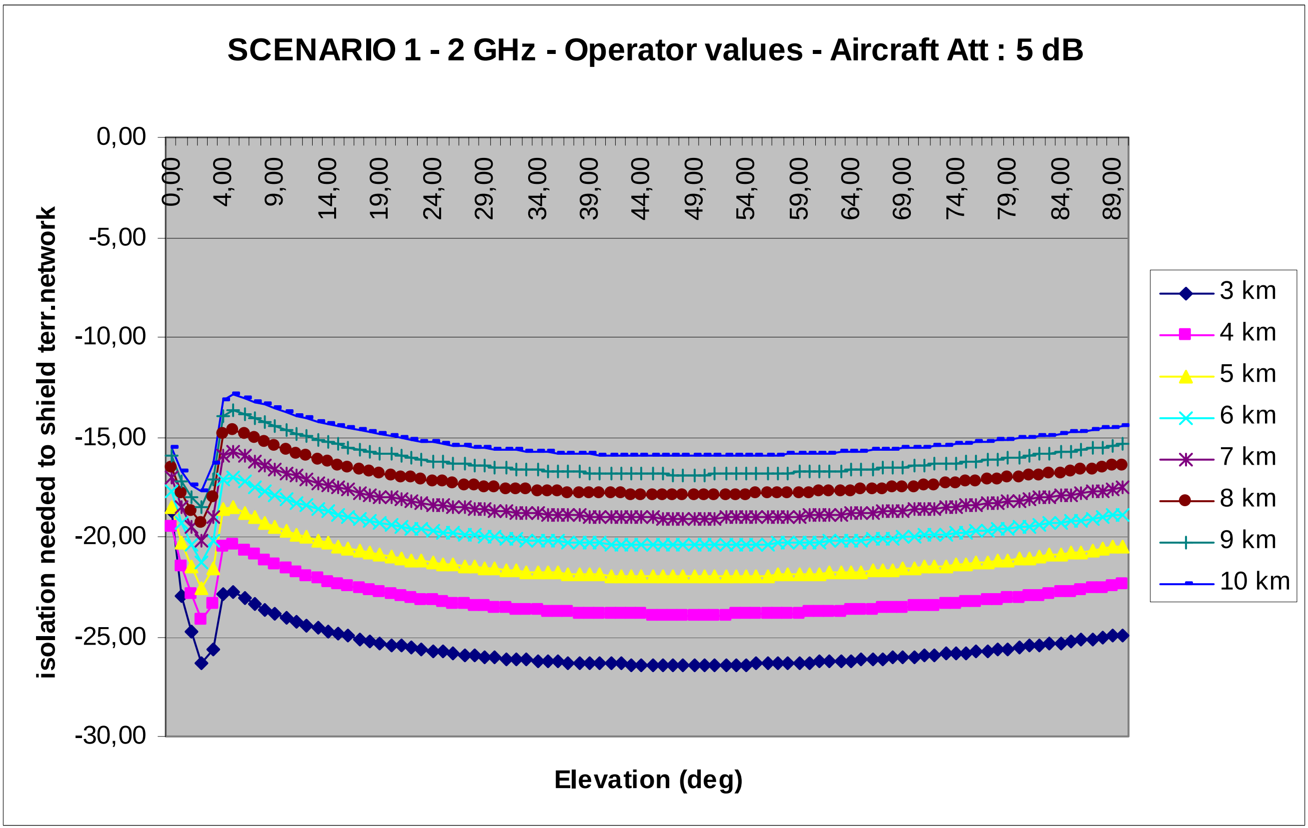
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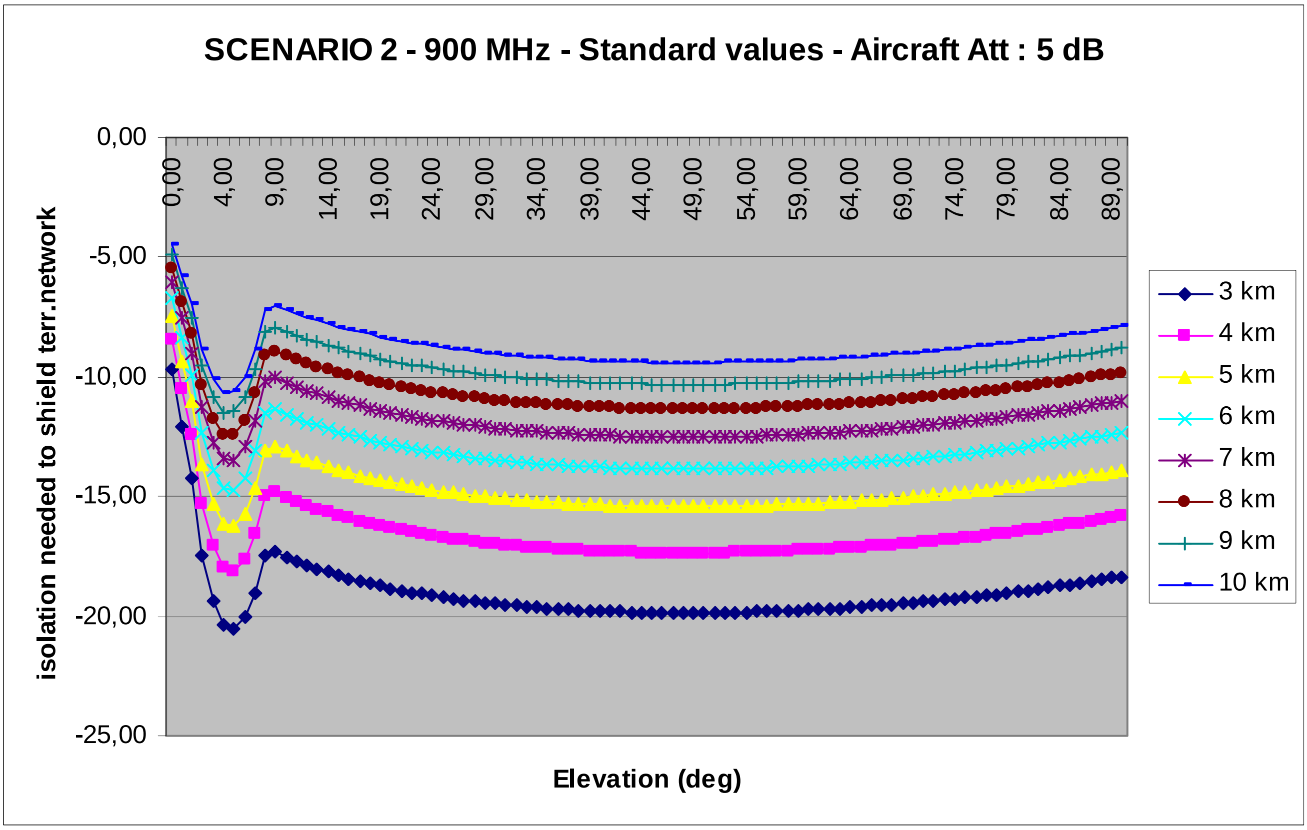
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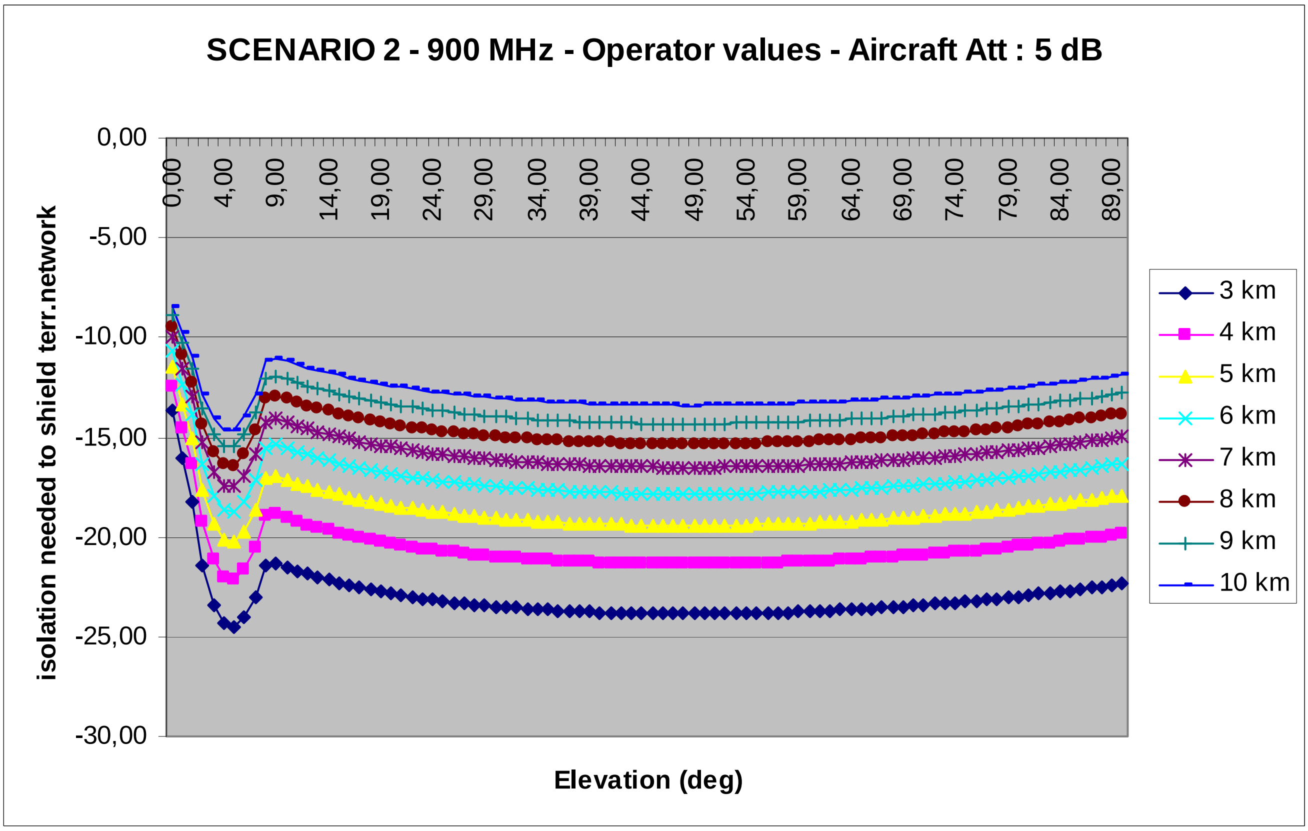
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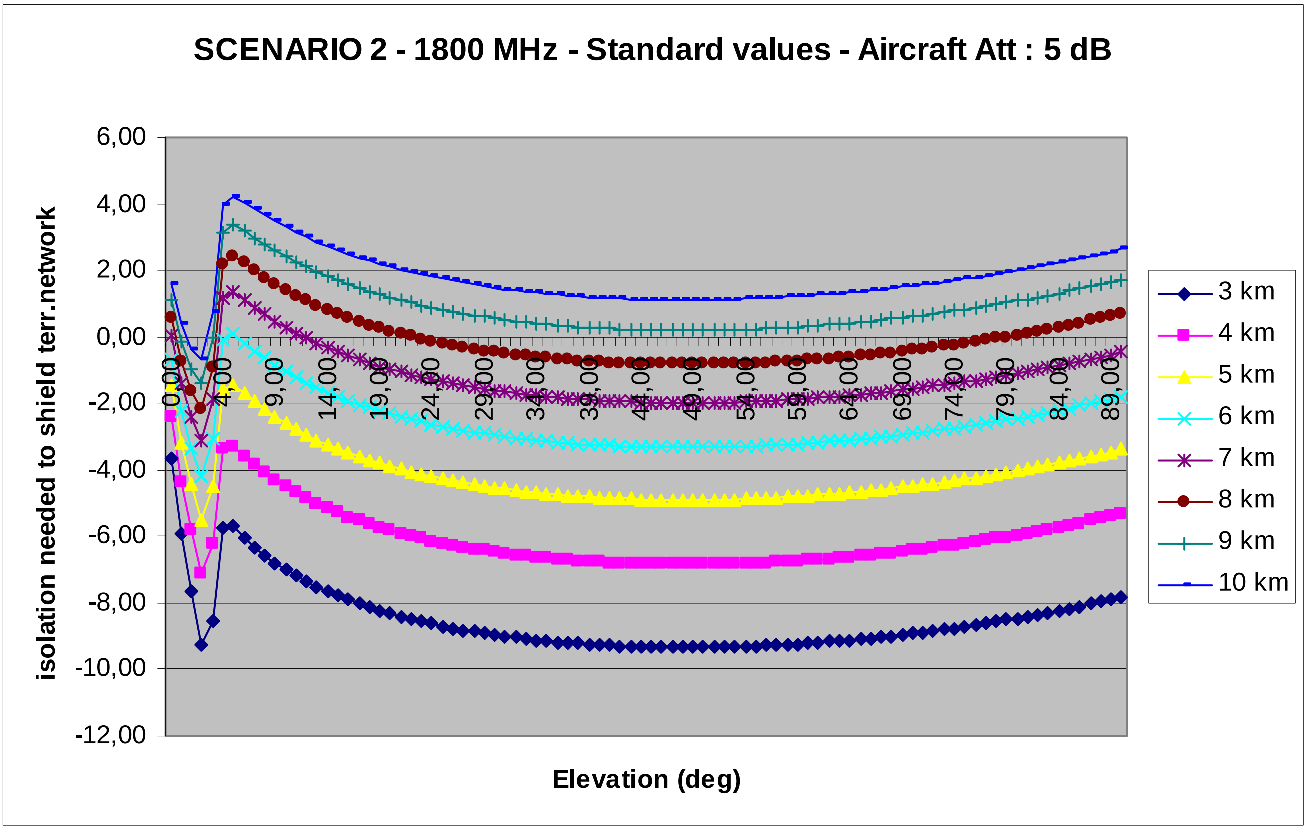
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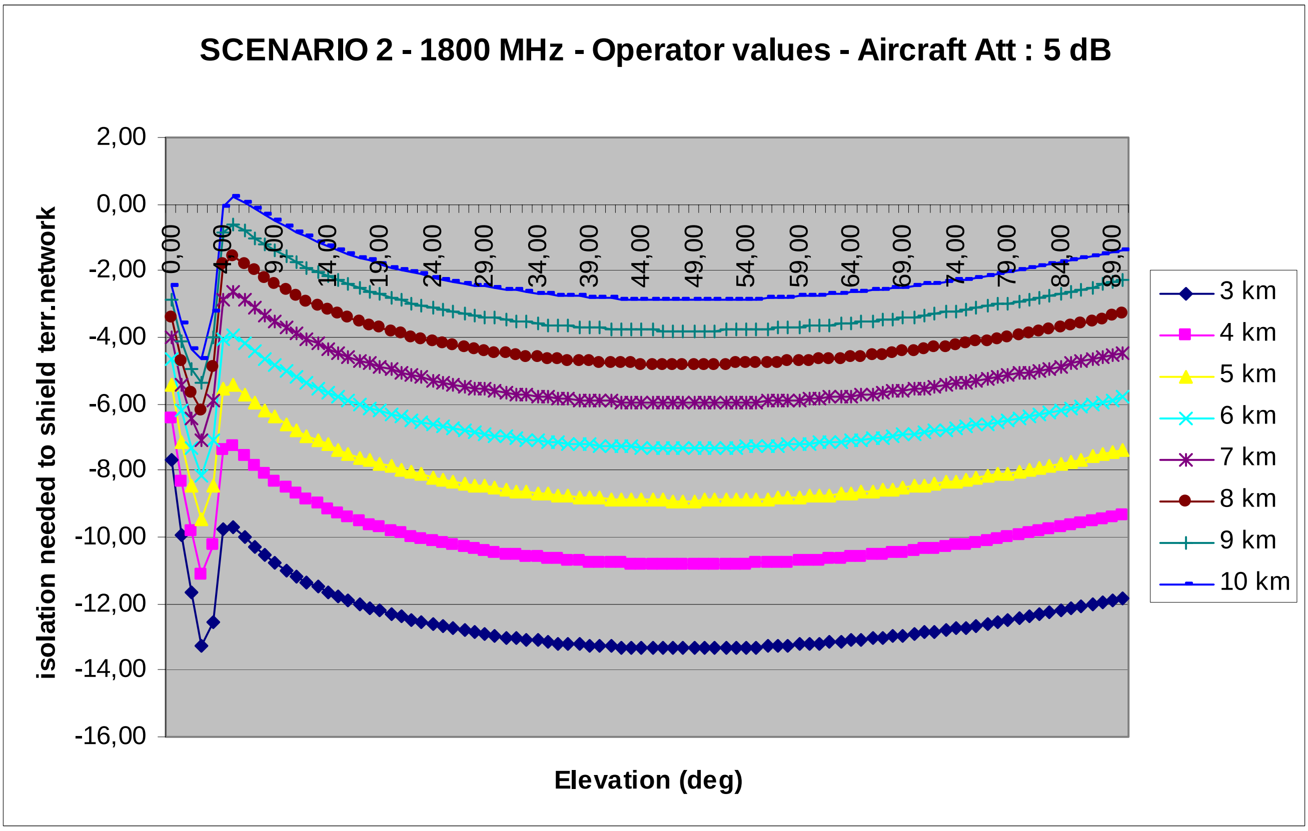
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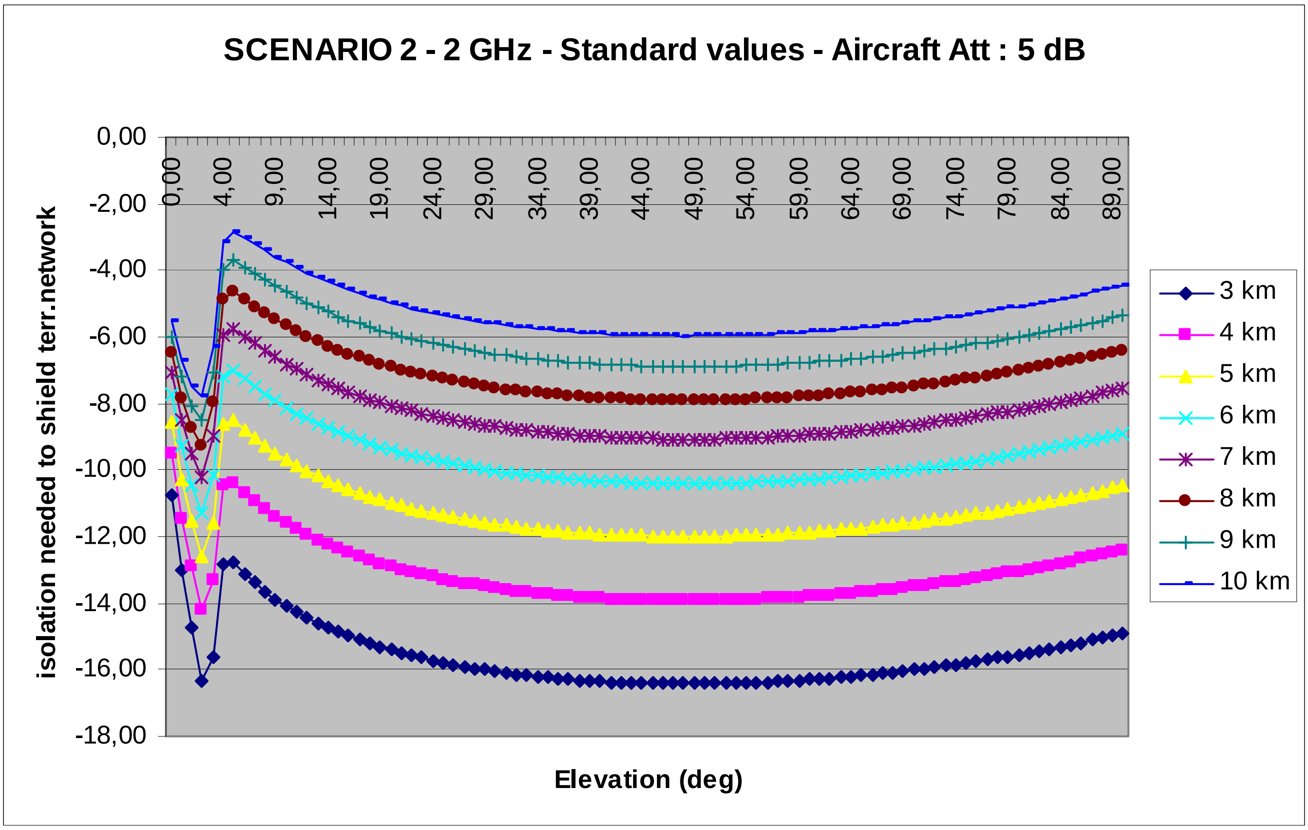
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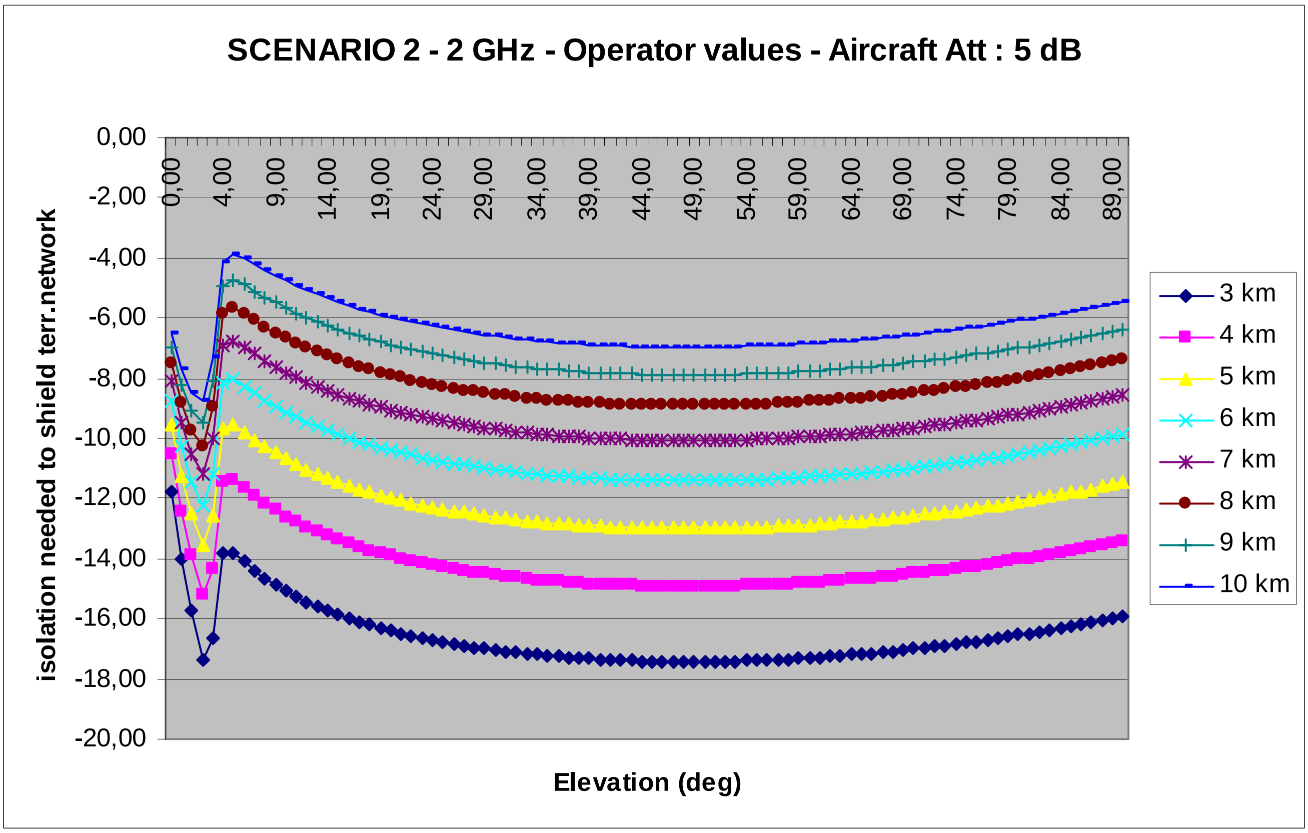
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ANNEX B : Considerations on leaky feeders

Modelling leaky feeders is a delicate problem, and several models exist. A recent paper by Qualcomm, presented as SE7(05)142, uses a model based on diffuse radiation from the cable cited from a paper by S.P. Morgan, “Prediction if indoor wireless coverage by leaky coaxial cable using ray tracing”, IEEE Trans Veh. Tech., Vol. 48(6), pp. 2005-2014, Nov 1999.

The idea here is to try to derive the results of Morgan and then use the same analysis to derive the EIRP seen from the ground, and finally compare with the assumptions made in SE7(05)142 Appendix A.

Hence our first problem is to determine the power from the feeder when a receiver is located aboard the aircraft at distance D << L, where L is the length of the feeder within the fuselage, and then to determine the EIRP from the feeder seen from the ground at a distance D >> L.

Turning to the first problem, the Morgan result assumes that each element of the cable radiates diffusely, that is, each segment is approximated by a point source that radiates incoherently according to the so-called Lambert’s law. Furthermore, it is supposed that the cable is “infinitely” long (that is D << L) and lossless. The power intensity radiated from a diffusely radiating element of length dl along the cable is thus assumed to be

(1) $$dp = \frac{\sin\theta}{(\pi r)^2}\Pi\, dl ,$$

where θ is the angle between the viewing direction and the cable axis, Π is the power radiated per unit length of the cable and r is the distance. (Integrating over a sphere, we get the total power Πdl.) The receiving antenna is assumed to be a half-wave dipole parallel to the cable, the directivity function of the former is (in the E-plane)

$$f(\theta) = 1.64\left[\frac{\cos((\pi/2)\cos\theta)}{\sin\theta}\right]^2 .$$

The total received power at a distance D from the axis of the (infinite) feeder is a sum of the power received from the incoherent point sources along the cable

$$P(D) = \int_{-\infty}^{\infty}\left[f(\theta)A_e\right]dp$$

where $A_e = \lambda^2/(4\pi)$ is the effective antenna area of an isotropic antenna. The factors within the square brackets thus represent the effective antenna area of the dipole in the direction θ. We then make the variable substitution $l = -D\cot\theta$, whence $dl = -D/\sin^2\theta$, and set $r = D/\sin\theta$ (see figure in [1]) to obtain

$$P(D) = \frac{\Pi}{\pi D}\left(\frac{\lambda}{4\pi}\right)^2 4\int_0^{\pi} f(\theta)\sin\theta\, d\theta$$

The integral is of the same type as that used when determining the radiation resistance, and luckily a close form result exists:

$$4\int_0^{\pi} f(\theta)\sin\theta\, d\theta = 2\cdot 1.64\left(\gamma + \ln 2\pi - \mathrm{Ci}(2\pi)\right) \approx 8.00$$

where γ = 0.5772… is Euler’s constant and Ci a Cosine integral (see mathematical table). Hence we obtain Morgan’s result

(2) $$P(D) = \frac{8\Pi}{\pi D}\left(\frac{\lambda}{4\pi}\right)^2 .$$

The program next is to determine the EIRP from the leaky feeder as seen from the ground by following the same analysis that resulted in (2) for the case in which D >> L. The key to this is thus (1), the power intensity of the incoherently radiating point sources along the cable. Integrating along the length of the feeder, we obtain the received power by an isotropic antenna as the sum

(3) $$P_{terr}(D) = A_e \int_0^L dp \approx \frac{\lambda^2}{4\pi} \frac{\sin\theta}{(\pi D)^2} \Pi L = \frac{4\Pi L \sin\theta}{\pi}\left(\frac{\lambda}{4\pi D}\right)^2 ,$$

This result is consistent with the well known fact that any finite sized radiator looks like a point source at sufficient distance. The aircraft (feeder) is assumed to be parallel to the ground and θ is the viewing angle. The maximum occurs in a direction normal to the aircraft, where the result $4/\pi \cdot \Pi L$ is very close to the Qualcomm assumption.

Hence Qualcomm's analysis is almost consistent with the theory in SE7(05)142 Appendix A, the difference is negligible.

Turning back briefly to the case in which D << L, there are alternative ways of deriving an expression for the received power from the feeder. Using the same notation, we note that the power intensity at a distance D from the feeder, assumed to be a cylindrical radiator, is

$$S(D) = \frac{\Pi}{2\pi D} .$$

The power received by an isotropic antenna of gain Ga is then

$$P(D) = S(D) G_a \frac{\lambda^2}{4\pi} = \frac{(2\pi G_a)\Pi}{\pi D}\left(\frac{\lambda}{4\pi}\right)^2 .$$

For a half-wave dipole $2\pi G_a = 10.3$ with the maximum gain 1.64, and we end up with a result close to (2). Both of the models are in fact approximations and either of them could be used. Cable attenuation is more easily included if one assumes an ideal isotropic antenna at the receiver end just like the last approach. The integrals above for the received power can then be solved explicitly.

Strictly, in order to obtain the radiated power intensity of the feeder, one should first have obtained the radiated electric and magnetic fields, which are coherent sums due to induced currents on the cable shield. The approach above is instead based on incoherently radiating sources and a power sum, which will not reveal the fast local variation of the radiated field: the fading pattern. However, in practice, it is impossible to determine the induced cable currents in the presence of surrounding objects, and the scattered local fields (within a few wavelengths) will vary randomly. Hence it appears to be reasonable to use a model based on incoherent scattering to obtain an estimate of the mean value of the radiated cable power. A fading margin can then be added in order to account for the local faster local variation of the received signal. Indeed, Morgan reports that the diffuse model above is more in agreement with measured data than a certain (deterministic) coherent model.